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CENTRAL VALLEY FISH AND WILDLIFE MANAGEMENT STUDY

TEMPERATURE AND FLOW STUDIES FOR OPTIMIZING CHINOOK SALMON PRODUCTION, UPPER SACRAMENTO RIVER, CALIFORNIA

SPECIAL REPORT
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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MID-PACIFIC REGION • SACRAMENTO, CALIFORNIA

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SUMMARY

This report presents the results of investigations regarding temperature and flow modifications and their on impacts chinook salmon in the Upper Sacramento River.

Since the 1970's chinook salmon population trends in the Sacramento River have declined. Studies indicate that unless substantial protective measures are undertaken, the trend of declining salmon populations will continue as developmnet of the river system continues.

Temperature and river flows are two of the most critical habitat requirements of chinook salmon. At present time, salmon in the Sacramento River are adversely impacted by water temperatures that are too warm during the fall months for optimum egg and fry survival and too cold during the spring for optimum growth. In addition, changes in river flow regime have resulted in aggravating the adverse effects of toxic pollutants entering the river disrupting salmon spawning, and decreasing egg and fry survival rates.

The specific study area included the Sacramento River from Keswick Dam (River Mile 302) downstream to Ord Ferry (River Mile 184) a distance of 18 miles. Also included are three Central Valley Project Reservoirs--- Clair Engle, Folsom, and Shasta as part of an analysis of the impacts to the reservior fisheries that would occur with alternative operations schedules.

The study team analyzed the future without conditions and formulated conceptual structural and nonstructural modifications which would enhance the fishery, while attempting to mainatain operational cost effectiveness.

Structural

The following three structural alternatives were analyzed:

Alternative 1 - Diversion Tunnel Modification

This concept uses the existing diversion and old Southern Pacific Railroad tunnel. Reservoir water would enter a horseshoue shaped conduit at a centerline elevation of approximately 651 feet and flow 1,364 feet to a bifurcation. This bifurcation would begin the new construction as the flow was diverted about 60 degrees to a 20 foot irrigation district concrete tunnel. Flow would then proceed through this new tunnel for 108 feet to a 20 foot diameter penstock which would feed three turbines. This alternative would allow cooler, lower level water to be released through the tunnel during the spawning season.

Alternative 2 - Multilevel Withdrawl Structural and Diversion Tunnel

This alternative consists of a combination of Alternative 1 and Alternative 3, the multilevel withdrawl structure described below.

Alternative 3 - Multilevel Withdrawl Structure

This alternative consists of a tubular steel framed structure which would attach to the side of Shasta reservoir, covering five penstocks. Water would enter the penstocks through a combination of louver type shutters and slide gates located at various elevations. This structure would draw water from the upper levels of the lake during the spring and summer months and conserve the colder water for releases during the salmon spawning period.

The three alternatives were evaluated and compared on the basis of the dollar cost of the alternative and the benefits to the salmon resources. The results of these comparisons are presented in the following table.

SUMMARY TABLE
Comparison of Structural Alternatives

	Alternative 1	Alternative 2	Alternative 3
Construction costs			
Estimated construction costs[a/]	11,839.000	32,810,000	20,971,000
Interest during construction[b/]	1,606,000	3,265,000	1,659,000
Total investment cost	13,445,000	36,075,000	22,630,000
Annual costs[b/]			
Annual investment cost	1,160,000	3,112,000	1,952,000
Annual OM&R costs	8,000	36,000	28,000
Total annual structural costs	1,168,000	3,148,000	1,980,000
Annual value of power losses[c/]	4,319,000	4,696,000	4,187,000
Total implementation costs	5,487,000	8,117,000	6,167,000
Salmon benefits			
Numerical reduction in mortality (No. of fish)	825	4,799	4,622
Annual cost per salmon saved	6,650	1,691	1,334

a/ January 1985 prices.
b/ Computed using Federal interest rate of 8.65% over 100-year planning period.
c/ Power losses at $1.15 per kWh.

Alternative 3 is the most cost effective for the the number of salmon saved however, alternative 2 has the greatest effect on improving conditions for the winter-run salmon which are presently considered to be the most susceptible to adverse environmental conditions in the Upper Sacramento River.

Nonstructural

Four alternative nonstructural flow scenarios were compated against a base condition to determine fishery impacts associated with each scenario. The impacts on chinook salmon in the Sacramento River were evaluated by a water temperature-fish mortality mathematical model. The impacts on the reservoir fisheries in three Central Valley Project reservior were evaluated by a reservior fishery mathematical model developed by the U.S. Fish and Wildlife Service.

Additional mathematical model simulations used in this evaluation include a hydrologic-water project operations model, a hydroelectric-power generation optimization model and an economics model.

The chinook salmon evaluation was severely hampered by the lack of a predictive method to assess flow-related impacts other than water temperature. Consequently, the evaluation must be recognized as a preliminary and partial assessment. In addition, there were no means of identifying reservoir water release schedules necessary to meet specified water temperature levels in the Sacramento River.

The results of the evaluation indicated that the river fishery would be negatively impacted by all of the alternative flow scenarios, power generation would be increased in three of the four scenarios and project firm yield water delivery capabilities would be reduced in all scenarios. Implementation of any scenario wuld result in a dollar loss compared with the base condition.

The reservoir fisheries would be unaffected by any of the alternative flow scenarios.

This study identified a need to develop a capability to quantify flow-related fish impacts in the Sacramento River and a need to develop a capability to predict flow release schedules necessary to meet specified river water temperature levels. An instream flow study such as the Instream Flow Incremental Methodology, and a river flow-water temperature optimization model would be extremely valuable in developing the necessary predictive capabilities.

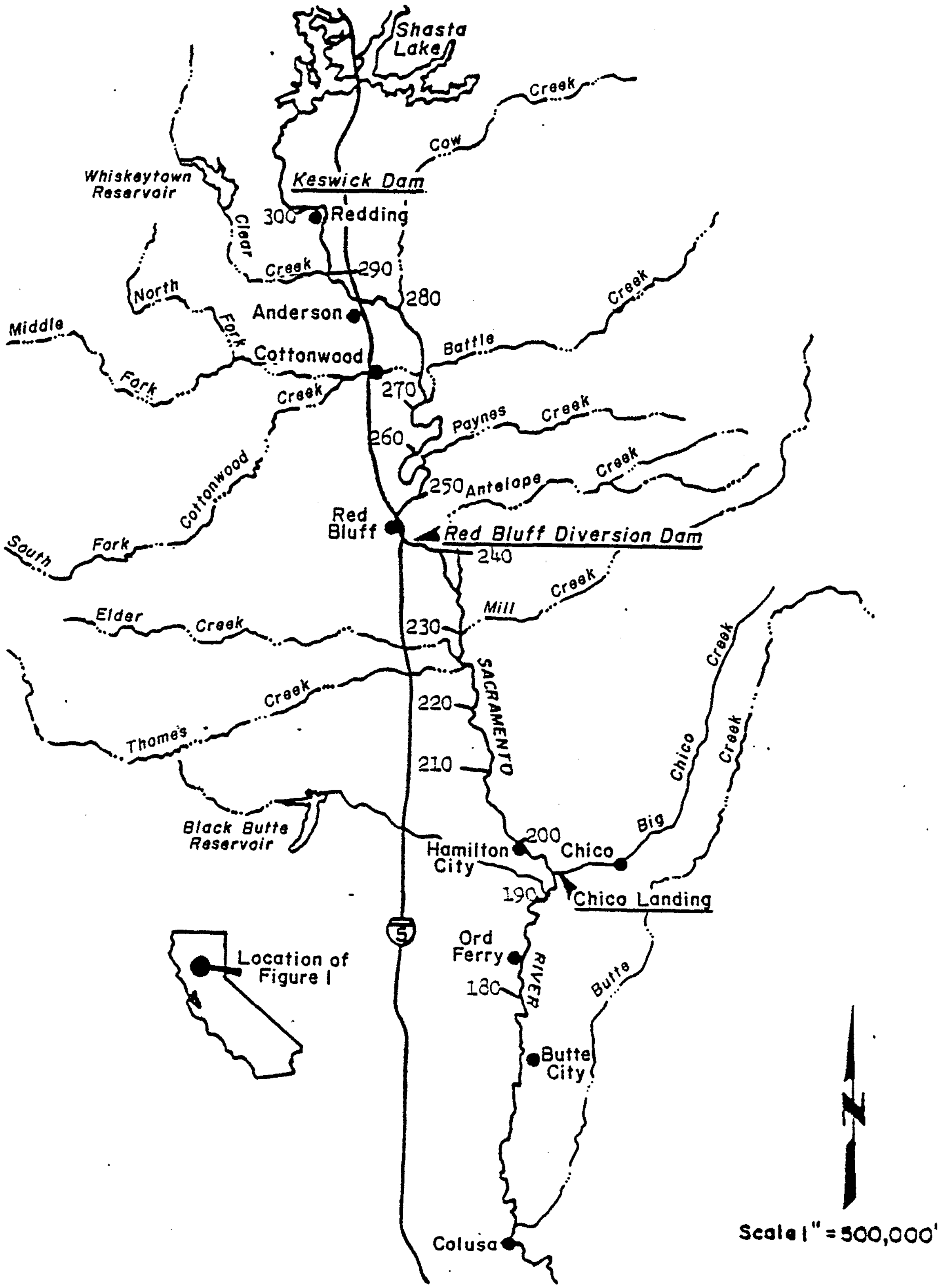

FIGURE 1.

Location map showing the study reach between Keswick Dam and Ord Ferry in Northern California.

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CHAPTER I

INTRODUCTION

The Sacramento River system is the largest and most important in California. Although covering only 17 percent of the State, it yields about 35 percent of the water supply and provides the most important salmon stream in the State--the Sacramento River. Chinook salmon originating from the Sacramento River system account for 80 percent of the commercial catch from San Francisco to Monterey, 40 percent of the North Coast catch, and 5 percent of the Oregon catch (Hallock, 1978).

Since the early 1970's, however, chinook salmon population trends in the Sacramento River have declined, causing great alarm within Federal, State, and local resource agencies and the general public. Various State and Federal agencies have conducted studies to determine how development of the river system--flow regulation, diversion, bank protection, and gravel mining--have impacted the fisheries resource. Results of these studies indicate that unless substantial protective measures are undertaken, the trend of declining salmon populations will continue as development of the river system continues.

Temperature and river flows are two of the most critical habitat requirements of chinook salmon. At the present time, chinook salmon in the Sacramento River are adversely impacted by water temperatures that are too warm during the fall months for optimum egg and fry survival and too cold during the spring months for optimum growth. Changes in the flow regime of the river have likewise affected the salmon by aggravating the adverse effects of toxic pollutants entering the river, disrupting salmon spawning, dewatering and killing eggs in the gravel, and stranding juvenile fish.

As salmon are the most manageable as well as the most valuable anadromous fish resource in California, measures to protect and enhance their temperature and flow habitat requirements need to be determined and implemented.

PURPOSE AND SCOPE

This report presents the results of investigations on the effects of temperature and flow modifications on chinook salmon in the Upper Sacramento River. Location of the study area is shown on Figure 1. Goals to protect or enhance salmon production are presented in this report, as well as potential alternative solutions to control temperatures and flows in the upper river. Three structural alternatives for modifying temperature and four nonstructural alternatives for modifying flows were identified and evaluated. In addition, an alternative which combined the structural and nonstructural plans was developed and analyzed.

The scope of the study was limited to identifying and quantifying the benefits of improved water temperatures and flows to chinook salmon in the Sacramento River from Keswick Dam downstream to Ord Ferry. The evaluation used existing data; no new data were developed. However, mathematical models were developed to determine the impacts of various temperature and flow schemes on the fishery.

Although five species of salmon are known to occur in the Sacramento-San Joaquin River Delta river system, chinook salmon (Oncorhynchus tshawytscha) account for 99 percent of the salmon in the Central Valley (Hallock and Fry, 1967). Therefore, habitat requirements for the chinook salmon were used in gathering and evaluating the data.

Cooperating in preparation of the report by the Bureau of Reclamation (BOR) were the staffs of the U.S. Fish and Wildlife Service (FWS) and the California Department of Fish and Game (DFG). Personnel from these agencies developed the goals and objectives of the study and reviewed the data which were developed.

STUDY AREA

The study area includes the Sacramento River from Keswick Dam (River Mile [RM] 302; elevation 405 feet, mean sea level [MSL]) downstream to Ord Ferry (RM 184; elevation 118 feet, MSL), a distance of 118 miles (Figure 1). Also included are three Central Valley Project (CVP) reservoirs--Clair Engle, Folsom, and Shasta. These reservoirs were evaluated as part of an analysis of the impacts to the reservoir fisheries that would occur with alternative operations schedules.

Sacramento River

The Sacramento River between Keswick Dam (RM 302) and the Red Bluff Diversion Dam (RM 243) has clear and fast flowing water. River geomorphology from Keswick Dam downstream 53 miles is stabilized by bedrock as evidenced by the narrow entrenched channel and low bank erosion rates (Buer et al, 1984).

The river is characterized as a meandering channel. In this context meandering does not imply channel migration, but is defined as a channel with an average sinuosity greater than 1.5. The predominant streambed material is large rubble and boulders. Gravel deposition areas are relatively scarce and typically occur at the inside of meander bends. In the vicinity of Redding (RM 300 - 280), gravel deposition areas are more common. Subsequently, the channel splits into numerous smaller ones around these deposition areas.

Urbanization and grazing are the most common land uses along this stretch of river. Adjacent terrain is steep and relatively resistant to erosion.

The Red Bluff Diversion Dam impounds Lake Red Bluff. The dam slows the water velocity upstream about 6 miles (RM 249). From Red Bluff (RM 243) downstream to Ord Ferry, the river is classified as a gravel-bed alluvial stream because it flows through its own alluvial deposits (Buer et al, 1984). The water is still relatively clear but has a lower velocity due to a decrease in slope. The river is graded and occupies a wide flood plain belt. The riverbed is sand, gravel, and cobbles. Gravel bars that split the channel are common in this reach. Throughout the reach a pool-riffle sequence is present. Riffles occur either in crossover areas between meander bends or adjacent to gravel bars, with pools located in meander bends. Bank erosion is common along this section of the river. The dynamic process of erosion and deposition of the eroded material creates ever changing stream habitat, including gravel bars and backwater areas. The predominant land use along this section of the river is agriculture, consisting primarily of walnut and almond orchards.

Since 1982, the lowest recorded discharge was 2,000 cubic feet per second (cfs), occurring in 1940 (Bend Bridge station, near Red Bluff); the maximum discharge recorded in 1944, measured 291,000 cfs (U.S. Geological Survey [USGS], 1980). Extreme water temperatures recorded at Bend Bridge for the 1955 to 1980 period are 39°F (1962) and 66°F (1976).

Introduction

Reservoirs

Three reservoirs--Clair Engle, Folsom, and Shasta Lakes--were examined in the analysis of the impacts of the nonstructural alternatives on reservoir fishery. Pertinent data on the reservoirs are shown in the following tabulation:

Reservoir	Clair Engle	Folsom	Shasta
Location (county)	Trinity	Sacramento Placer, El Dorado	Shasta
Area draining in reservoirs (square miles)	692	1,861	6,400
Mean surface area (acres)	13,550	10,000	13,550
Volume (acre-feet)	1,941,600	713,000	4,500,000
Mean depth (feet)	137	66	152
Maximum depth (feet)	385	226	490
Annual water level fluctuation (feet)	60	53	55

Each reservoir supports both a cold- and warmwater fishery. Species common to all the reservoirs include kokance salmon, rainbow and brown trout, brown bullhead, white catfish, green sunfish, and large- and smallmouth bass. Folsom and Shasta Reservoirs also include white sturgeon, threadfin shad, channel catfish, bluegill, golden shiner, and carp.

About 80,000 rainbow trout are planted annually at Clair Engle Lake to sustain a put-and-take fishery. Lack of cover habitat limits sunfish production at the lake. Three factors limiting the potential of the fishery at Shasta Lake are (1) water-level fluctuation during the spawning season which limits the reproductive success of sunfish (2) limited cover for sunfish and (3) heavy metals pollution entering the Squaw Creek arm of the reservoir which results in occasional fish kills.

RELATIONSHIP TO CENTRAL VALLEY FISH AND WILDLIFE MANAGEMENT STUDY

This report is one of a series of reports being completed under the Central Valley Fish and Wildlife Management Study, initiated in 1978, to formulate a comprehensive framework of fish and wildlife management guidelines for the Central Valley. The study area shown on Figure 2 is the Central Valley hydrologic basin. A comprehensive approach is essential to resolve the very complex and controversial water-related fish and wildlife issues.

Water resource development and use within the valley are so interrelated that localized modifications of water, land, and fish and wildlife management practices often result in corresponding impacts elsewhere in the valley. Any actions, such as modernization of fish hatcheries, streamflow alterations, and modification of control structures, cannot be pursued effectively without knowledge of the positive and negative impacts on beneficial uses throughout the system. The comprehensive study of existing basinwide conditions is being made so that the impacts of proposals to resolve existing fish and wildlife problems or the development of new wter supplies can be evaluated adequately.

Three categories of problems and opportunities are being analyzed in the overall study. They are (A) anadromous fish, (B) wildlife, and (C) reservoirs and miscellaneous. Studies being conducted under the anadromous fish and reservoir and miscellaneous category are shown in Table 1. The problems addressed in this report are A-1 and C-2.

FIGURE 2

CENTRAL VALLEY

FISH AND WILDLIFE MANAGEMENT STUDY-CALIF

CENTRAL VALLEY HYDROLOGIC BASIN

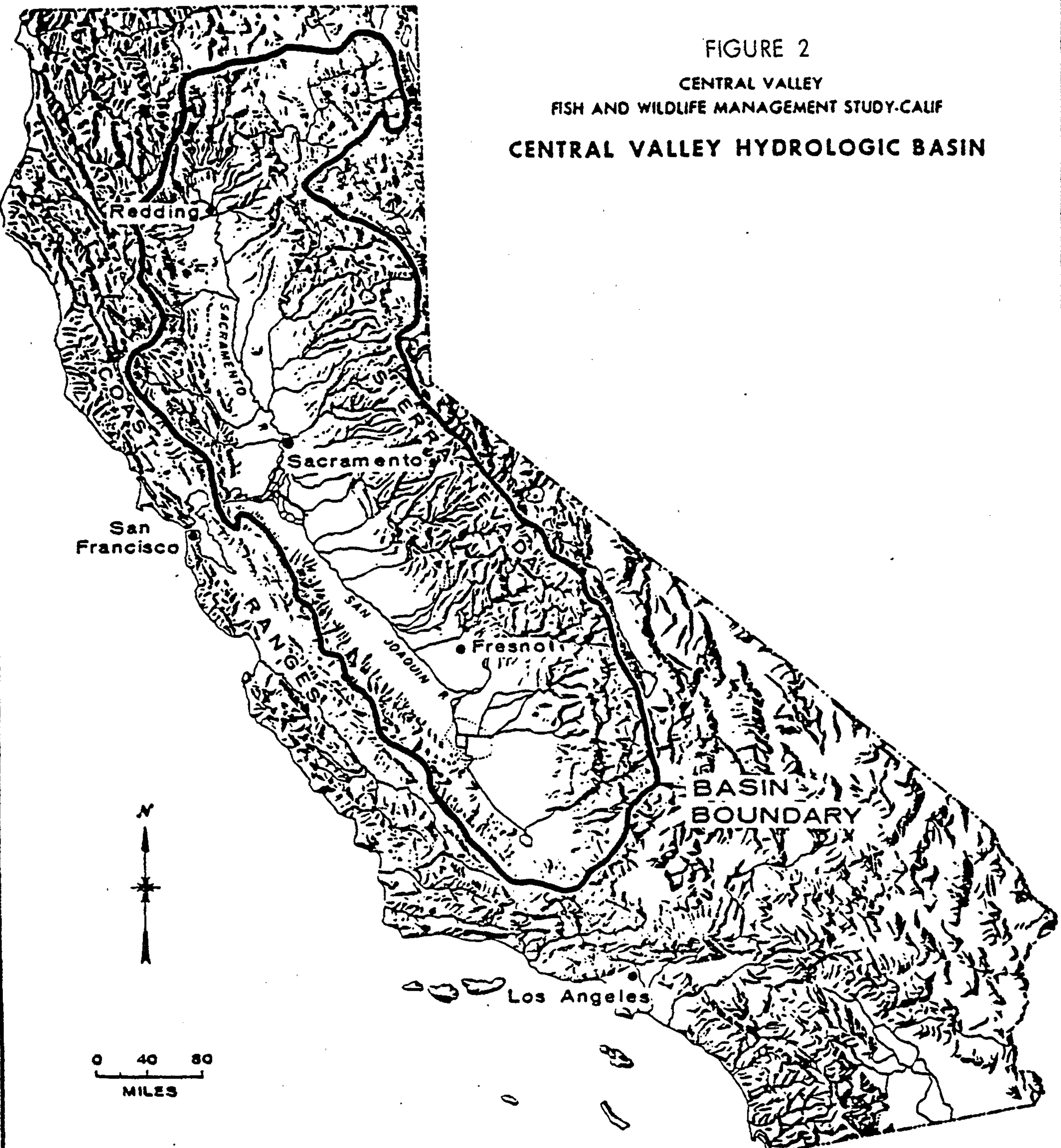

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TABLE 1

Anadromous Fish and Reservoir Studies
Central Valley Fish and Wildlife Management Study

Problem No.	Description a/
	Anadromous Fish
A-1	Determine the flows required in the Upper Sacramento River to provide for all freshwater life stages of salmon at various population levels
A-2b/	Determine whether fish passage at Red Bluff Diversion Dam is a problem and if so, formulate a solution (December 1985)
A-3	Evaluate the disturbance that operation of the ACID's dam at Redding may have on salmon spawning and egg incubation and its significance to all affected fish populations and formulate possible solutions to problems if needed (July 1983)
A-4b/	Evaluate the status of Tehama-Colusa Canal fish facilities, including screens to canal intake and develop recommendations for resolving problems and making improvements (December 1985)
A-5	Investigate the status of the salmon spawning habitat in the Upper Sacrmento River and develop recommendations for resolving problems and making improvements.
A-6	Determine the need for additional support for ongoing evaluations of Coleman National Fish Hatchery and Keswick Fish Trap operations and provide this support if necessary
A-7	Evaluate the potential of a comprehensive restoration program for San Joaquin salmon and identify the actions required to accomplish this.
A-8	Evaluate the need for fish screens on diversion facilities along the Sacramento River.
A-9b/	Evaluate the disturbance that operation of Red Bluff Diversion Dam may have on salmon spawning and egg incubation and evaluate its significance to all affected fish populations, and formulate corrective measures if needed (December 1985)
A-10	Determine whether predation of anadromous fish in the Upper Sacramento River is a problem and if so, formulate a solution (March 1983)
~~A-11~~c/	~~Evaluate the~~ potential for improving the production of anadromous fish in tributaries to the Sacramento River
A-12	Investigate the need and potential of enlarging Nimbus Fish Hatchery.
	Reservoirs and Miscellaneous
C-1	Formulate and evaluate alternative solutions to the heavy metal toxicity originating from Spring Creek drainage
C-2	Formulate the need and potential of controlling water temperatures in the Sacramento River to optimize production of resident fish in major reservoirs in the Central Valley.
C-3	Formulate a program to optimize production of resident fish in major reservoirs in the Central Valley
C-4	Evaluate the impacts of turbidity on fish and sport fishing in the Sacramento River and determine what measures could be taken to resolve any serious problems identified
C-5	Evaluate the need for additional fishing access at existing major water proejct facilities and develop appropriate recommendations
C-9d/	Evaluate the benefits and cost of increased flows in Clear Creek for fish production.

a/ If study has been completed, publication date of report is shown in parentheses.
b/ Problems A-2, A-4, and A-9 were combined and released as a single report.
c/ Problem A-11 was deleted.
d/ Problems C-6, C-7, and C-8 were omitted from the study as they were being adequately addressed in studies of other agencies.

RELATED INVESTIGATIONS

Previous Investigations

Temperature Studies. In 1971 Don Weidlein (DFG) completed temperature approximations which indicated fall release temperatures from Shasta Lake would be too warm for salmon spawning in the Sacramento River during years of low storage (Weidlein, 1971). Temperature prediction studies completed in 1971 by Jack Rowell of BOR further defined the temperature problem and found selective withdrawal at Shasta would provide some downstream temperature control, although not enough to completely correct the temperature problem in all years or at all locations on the river (Rowell, 1972).

The full extent of the temperature problem was realized during the drought of 1976 and 1977 when Shasta storage levels dipped to record lows. In 1976, the problem was partially controlled by modifying operations and importing colder water from Clair Engle Lake. This operational flexibility was lost during 1977, however, when storage in Clair Engle became too low. During the drought, various temporary solutions were evaluated by the BOR and DFG. One of the solutions included a temporary cable-supported plastic curtain designed by CH_2M Hill for DFG and was estimated to cost $500,000 (DFG, 1977). A DFG temperature study predicted that the curtain along with modified CVP reservoir operations would provide satisfactory temperatures below Keswick Dam in October and November (Weidlein, 1977). The curtain was not installed, however, due to concerns about potential toxicity from Spring Creek drainage. A barrier was installed near Balls Ferry to prevent upstream salmon migration.

In 1978, BOR completed a selective withdrawal modification of Flaming Gorge Dam in Utah at a cost of about $4,600,000. The system is an add-on unit of movable shutters attached to the three power intake structures. The system allows withdrawal of water from any level in the upper 220 feet of the reservoir. The three modified intake structures operate independently to provide more sutiable downstream temperatures for fish than were previously available. The Flaming Gorge shutter system was installed by divers without modification to the existing structure (except for trashrack removal) and with no interference to normal operations (Peters, 1978).

Even though many studies have been conducted to define the relationship between temperature and fish survival (Brett, 1952 and 1956; Olson and Foster, 1955; Combs and Burrows, 1957; Orsi, 1971; Coutant, 1973; and Healey, 1979), these results are not directly applicable to this study because of several important differences.

First, these experiments occurred under laboratory conditions, where factors, such as density, predation, disease, and the availability of food and oxygen, are controlled. In the wild, as water temperatures approach lethal levels (sublethal), losses to predation and disease that would not otherwise occur often result. Work conducted by Coutant (1973) suggests that chinook salmon juveniles are more susceptible to predation following sublethal exposures to high temperature.

Secondly, these studies involve different exposure periods with most focusing only on short-term effects (several minutes to a few hours) and only a few extending more than a week because of the problems associated with maintaining suitable controls to prevent interference from other factors. The temperature regime of the Sacramento River shows considerable fluctuations, influenced by flow and ambient air temperature. There are fundamental problems with taking the results of short-term experiments that involve constant test temperatures and then applying them to a dynamic system where the emphasis is on the long term (several months).

Thirdly, most experiments include a period of acclimation which has shown to be an important factor in the range of temperature extremes that test organisms can withstand. It has been demonstrated that within limits, raising acclimation temperature results in an increase in the upper lethal temperature. Because the water temperature of the Sacramento River varies considerably within a 24-hour period, inclusion of the effects of acclimation in the computer model would be extremely difficult.

Finally, temperature induced mortality is not constant over time, but occurs at distinct points of development, e.g., "eyed stage" (egg) and upon yolk absorption (fry). This conclusion is supported by Johnson and Brice (1953) and by Olson and Foster (1955) who suggest that early embryological damage can occur without its manifestation until some later stage of development.

Flow Studies. The DFG has initiated a study of fish flow requirements in the Sacramento River. The study includes an intensive field data collection effort following the Instream Flow Incremental Methodology developed by the FWS. The DFG study will require several years to complete and will be actively supported by participation of the California Department of Water Resources (DWR), the National Marine Fisheries Service (NMFS), BOR, and FWS. Information developed in the DFG study will be used to support the flow levels required to sustain various fishes in the Sacramento River.

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Current Investigations

Chinook salmon runs in the Upper Sacramento River have declined since the peak runs counted 30 years ago. Several possible causes, other than toxic metal pollution, may be contributing to the decline. Numerous investigations of the chinook salmon fishery of the Upper Sacramento River are being conducted by the BOR and others. BOR studies, conducted under the umbrella of the Central Valley Fish and Wildlife Management Study, are listed on Table 1.

The three related fisheries studies associated with Red Bluff Diversion Dam and Tehama-Colusa Canal Fish Facilities (A-2, A-4, and A-9), were combined and analyzed in a single study and report ("Fishery Problems at Red Bluff Diversion Dam and Tehama-Colusa Canal Fish Facilities"). This report will serve as an information resource document for three ongoing action programs under BOR direction: (1) The Interim Action Measures Program to implement measures for resolving fish-related problems at Red Bluff Diversion Dam and Fish Facilities, (2) the Red Bluff Diversion Dam Fish Passage Action Program to develop a method for improving both upstream passage and downstream migration at the dam, and (3) the Tehama-Colusa Canal Diversion and Fish Passage Problem Action Program to correct problems at the canal intake and the fish facilities.

The Upper Sacramento River Salmon and Steelhead Advisory Committee was appointed by the Director of DFG in December 1982 to identify causes of fishery decline and make recommendations for the restoration of the fishery. To date, the committee has issued reports on Red Bluff Diversion Dam and Coleman National Fish Hatchery.

Introduction

In January 1982, the BOR and DWR initiated the Enlarging Shasta Lake Feasiblity Study. Actions recommended under that study, if implemented, could impact the amount of flow released to the Sacramento River. An enlarged Shasta Lake may be able to provide greater dilution capability than the present facilities. The study has been deferred, however, until a method of conveyance for the additional supplies is selected. Authorization and construction of an enlarged Shasta Lake is not expected until after the year 2000.

There is a priority to maintain all four races of chinook salmon for their inherent values and enhance those that are below their potential sustainable level. The FWS Mitigation Policy (Federal Register 46:15, January 23, 1981) provides internal guidance for establishing appropriate compensation for projects under the FWS purview. Under this policy, resources are divided into four categories to assure that recommended compensation is consistent with the fish and wildlife values involved.

In accordance with this policy, FWS has designated the freshwater habitat for the winter-run chinook salmon as Resource Category 1 because of the limited distribution, depressed state and unique life history of the fish. As a result of classifying habitat for the winter-run as Resource Category 1, some habitat for other races is also protected at the Resource Category 1 level. The FWS has designated the freshwater habitat of the fall, late-fall, and spring-run chinook salmon as Resource Category 2. Under this category, the mitigation goal is no net loss of in-kind habitat value.

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BACKGROUND OF SALMON DECLINE IN SACRAMENTO RIVER SYSTEM

Pre-Development Conditions

Before the interbasin transfer of water began with its subsequent development of dams and weirs on the Sacramento River system, the river was free-flowing and unregulated. During the winter, flows were high, often spilling over into the flood plain, while summer flows were low, averaging only 3,000 cfs. During this period, water temperatures in the Keswick to Colusa reach were often too high for salmon spawning and contributed to low egg survival when the fish did spawn.

Two upriver migrations of adult chinook salmon were recognized, the largest in the fall and a somewhat smaller one in the spring. A minor winter run was also reported (U.S. Department of the Interior, 1940). Partial counts from 1937-39 showed that the mean annual run past the present site of Shasta Dam exceeded 27,000 salmon although historically the number was probably considerably higher.

Most of the spring run, some of the fall run, and all of the winter run salmon migrated past the damsite to spawn in the Upper Sacramento, Pit, and McCloud Rivers. Above the damsite, the Sacramento River was a typically mountain stream, with innumerable pools, rapids, and gravel beds, providing ideal spawning habitat for salmon. The Pit River, a much larger stream than the Sacramento, provided spawning habitat in its main stem and in its tributaries up to Pit River Falls, which until a fishway was blasted, were impassable for salmon. The two most important salmon streams in terms of the number of spawners were the McCloud River, draining the south side of Mt.

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Shasta, and Battle Creek, draining the northwest of Mt. Lassen. The McCloud River, a tributary to the Sacramento River upstream from the present site of Shasta Dam, was accessible to salmon for 46 miles to Lower Falls (U.S. Department of the Interior, 1940).

A large number of fall-run salmon used the main Sacramento River below Redding. According to Rutter (1903):

> In ordinary years when the river was in normal low-water condition, the principal spawning beds of the fall salmon were in the portion of the main river in the vicinity of Red Bluff and Tehama. In November 1900, the river was examined carefully between the mouth of Battle Creek and Tehama. Few salmon were seen until within a few miles of Red Bluff, but from that point on every riffle was covered with spawning beds and dead salmon were everywhere apparent.

An Interior salmon-spawning survey (1940) estimated the potential use by female salmon in the 50 miles between the Shasta damsite and Bend Bridge to be 25,822, and reported many short stretches of riffle area suitable for spawning in years of low water, such as the fall of 1939.

Because of low spring and fall flows and high water temperatures, smaller streams on the west side below Red Bluff have probably never supported salmon although Thomes and Stoney Creeks may have supported sizable runs in the past. East side streams--Antelope, Mill, and Deer Creeks--were and remain important spawning areas, supported sizable runs of both fall and spring salmon.

Development of the River System

Some of the more important events and developments affecting the Sacramento River salmon fishery are discussed in the following paragraphs.

Commercial Fishing. Between 1873 and 1910, as many as 21 canneries processed 5 million pounds of salmon annually from the Sacramento-San Joaquin

River system. The 1882 commercial catch from the Sacramento River alone was 12 million pounds (DFG, 1965). Between 1912 and 1957, when commercial fishing was banned in the river, there was a 60-percent drop in the commercial catch. The end of commercial fishing led to a concomitant rise in the ocean fishery. In the last decade, it is estimated that the Sacramento River chinook salmon stocks contributed about 4.5 million pounds yearly, with a dockside value of about $10 million, to the commercial fishery. Sports fishing takes a small, but significant, part of the total catch.

Dredging and Hydraulic Mining. These practices, widespread from 1850 to 1885, are the chief causes of large unnatural sediment loads in the river channels until about 1940. During this time about 1.4 billion cubic yards of silt, sand, and gravel were washed into the river. Although no accurate records exist, it is probable that mining had a devastating effect on salmon spawning in the American, Yuba, and Feather Rivers. The effects of high sediment loads and turbidity on upstream and downstream migrating salmon in the study area is not known. Some dredge mining occurred on the Upper Sacramento River and on Clear Creek, both near Redding.

Toxic Mining Waste. Inactive mines near Redding continue to leach high concentrations of copper, zinc, and cadmium into the river, which can result in substantial fish kills during winter periods when storm runoff from the mine area is high and Sacramento River flow are low. Although the Spring Creek Debris Dam was constructed by BOR in 1963 to control the flow of pollutants into the main stream of the river, pollution remains a formidable problem especially when a season of heavy rain follows a season of drought such as occurred in 1976 and 1977.

the rapid expansion of the mining industry. First to be converted to agriculture were the fertile rim lands, which were higher than the surrounding tule lands, closer to water transportation, and less prone to flooding. Low levees were built to protect the crops. Through a series of laws passed between 1855 and 1968, the State sold the tule, or swamp and overflow lands, to farmers, who were obligated to reclaim them individually or through the formation of reclamation districts. Within a period of 3 years following the last act, practically all such lands had passed into private ownership (Jones, 1967).

Problems of flood control in these low-lying areas over the years led to the construction of the Sacramento River Flood Control Project, now consisting of over 440 miles of river, canal, and stream channels, 1,000 miles of levees, five major weirs, two sets of outfall gates, three major drainage pumping plants, 95 miles of bypasses, five low-water check dams, 50 miles of drainage canals and seepage ditches, and many smaller structure (Jones, 1967). More recent developments were the construction of Shasta and Keswick Dams, the Trinity River Project and the Red Bluff Diversion Dam.

Flood control and irrigation have caused numerous problems for anadromous fish. During late spring and early summer, tens of millions of downstream migrant chinook salmon have been and in some cases still are trapped in improperly screened or unscreened irrigation diverisons and pumping facilities on the Sacramento River system.

Before screening of the Glenn-Colusa Canal pumps, 10 million salmon fry are estimated to have died annually at this facility (BOR, 1972). During the

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fall, irrigation and/or power diversions from the tributaries to the river dry up portions of the streams and stop fish migration past the diversion structures.

Early dams and diversions built by miners and farmers blocked miles of habitat without allowance for fish passage. By the 1920's at least 80 percent of the Central Valley spawning grounds had been cut off by obstructions (BOR, 1972). The construction of Shasta Dam required 7.1 million cubic yards of stream gravel from the Redding area, and Shasta and Keswick Dams eliminated 40 percent of the pre-Shasta spawning area north of the Feather River (U.S. Department of the Interior, 1940). This loss is partly offset by the Coleman National Fish Hatchery and by increased spawning below Shasta Dam, which is facilitated by cooler fall water temperatures and increased flows. Gravel movements from areas above the dam were halted, however, and high releases have scoured and armored the channel downstream to at least Clear Creek (DWR, 1980). The effect of the Trinity River diversion on the Sacramento River salmon is unknown, but is estimated to be negligable.

Channelization and Bank Protection. Channelization and bank protection of the river between Red Bluff and the Sacramento-San Joaquin Delta eliminates and degrades habitat by increasing the depth and/or velocity of flow and by reducing the hydrologic diversity. Bank protection also reduces the amount of fresh gravel available through bank erosion. Schaffter et al (1981) also found that salmon densities at three paired riprap and eroding bank sites indicated an average of only one-third the number of fry in the riprap versus cutback areas.

Red Bluff Diversion Dam. Frank Fisher (DFG, Redding, personal communciation) indicates that the estimated mean annual spawning population above Red Bluff declined significantly after the diversion dam began operation in 1967. In contrast, the number of spawners below the dam has increased gradually since that time. Counts of chinook spawners below the dam area available from 1956 to the present. From 1956-59 the estimated mean annual spawning population was about 12,000 fish, dropping to 9,000 from 1960-69. From 1970-79 the estimated mean increased to 33,000 fish and has been maintained at that level. The DFG and the FWS have concluded that the dam is a partial barrier to upstream migrants and contributes to the mortality of downstream migrants (Hallock, 1978).

Urbanization. The trend toward urbanization, primarily in the vicinity of Redding, Anderson, Cottonwood, and Red Bluff, has caused additional fish habitat problems in the study reach. Standard gravel extraction for highways, housing, and other projects averages more than 1.3 million cubic yards per year in Shasta County and 0.5 million in Tehema County. Waste water from industries and sewage plants also affects the salmon.

Predation. The mortality of young salmon downstream migrants as a result of predation is substantial. Squawfish, trout, steelhead, striped bass, herons, mergansers, largemouth bass, and American shad feed extensively on salmon fry. Some of these predators are introduced species. American shad were introduced in 1871 and striped bass in 1879. These predator species have thrived in the Sacramento River to the detriment of the salmon.

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Introduction

Predation below the diversion dam is substantial. Water released from the bottom of the dam causes turbulence and reverse surface flow. This causes juvenile fish to become confused and disoriented, making them easy prey for a large concentration of predators that feed directly below the dam (DWR, 1984).

CHAPTER II

PROBLEMS AND NEEDS

Construction of Shasta Dam and its integrated operation as part of the Central Valley Project have drastically altered the flow regime and thermal characteristics of the Sacramento River. Before the construction of Shasta Dam, the riverflow typically receded in the late spring and water temperatures rose. June and July water temperatures recorded in Redding, California, in 1943 were in the range of 60° to 70°F. After construction of the dam, large quantities of cool water were released in the spring and summer for irrigation. In addition to the altered flow and temperature regime, the dam blocked acess for winter- and spring-run chinook salmon to the upstream areas, such as the McCloud River, where suitable temperatures are maintained throughout spring, summer, and fall (Slater, 1963).

LIFE HISTORY OF CHINOOK SALMON IN THE SACRAMENTO RIVER

The temperature and flow problems are complicated by the presence of four different races or runs of chinook salmon which spawn annually in the Sacramento River. These are the fall-, late fall-, winter-, and spring-runs. Life history characteristics of the salmon are shown in Figure 3. Chinook salmon counts at Red Bluff Diversion Dam are listed on Table 2.

Fall-Run Salmon

Fall-run salmon are the most numerous, migrating into the Sacramento River from July through December and spawning from early October

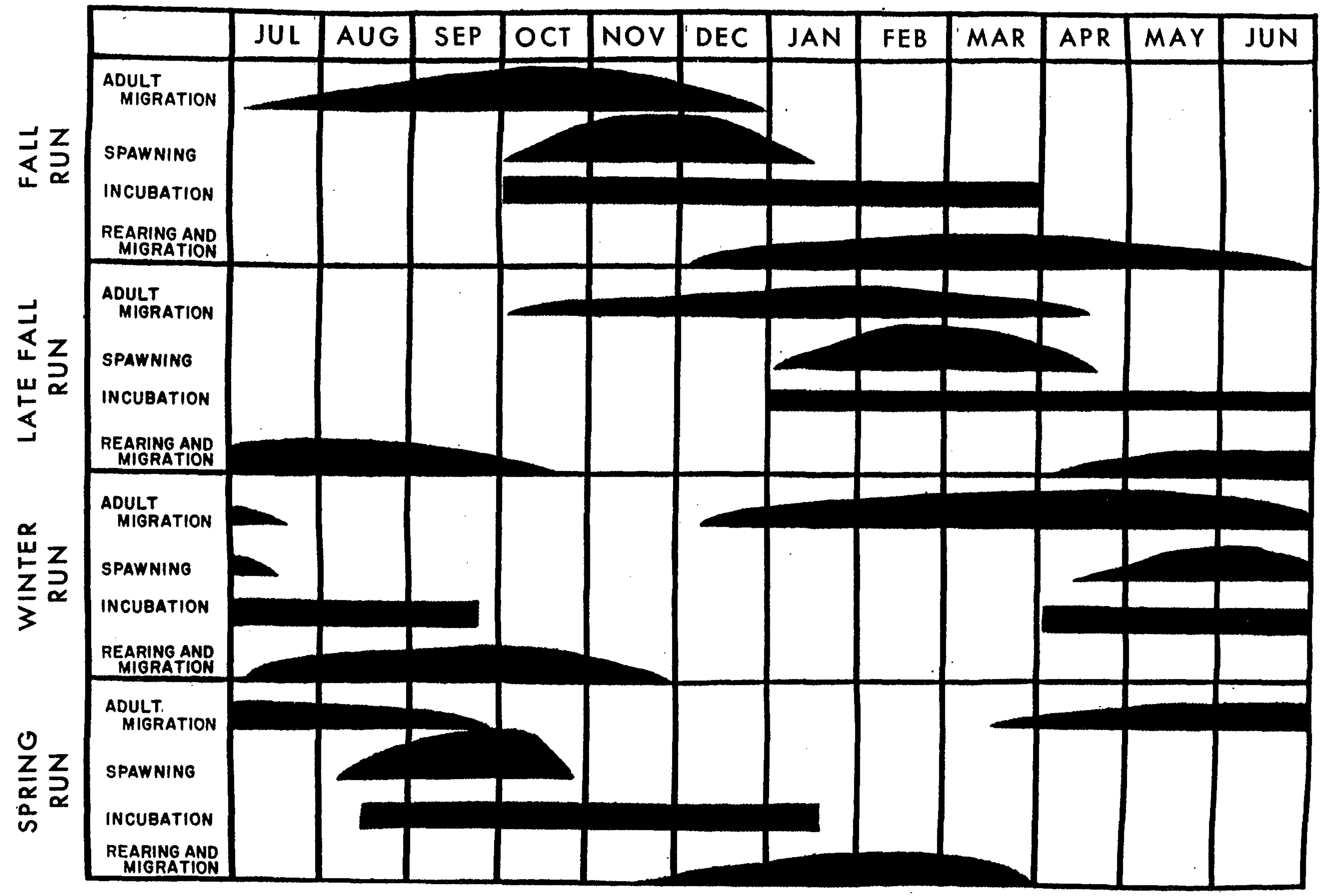

FIGURE 3. **Life history characteristics of chinook salmon in the Sacramento River.**

Table 2. Chinook salmon counts at Red Bluff Diversion Dam, 1967-1983 (Leidy, et. al , 1984)

Year	Late Fall	Winter	Spring	Fall	Total Salmon
1967 a/ b/	32,891	49,533 c/	23,441	99,040	204,905
1968 a/ b/	30,996	84,414 e/	14,446	134,995	264,851
1969 a/ b/	8,899 d/	117,808 e/	26,471	175,105	328,283
1970 a/ b/	16,567	81,159 f/	3,652	88,385	189,793
1971	16,741	53,089	5,830	63,918	139,578
1972	32,651	37,133	7,346	42,503	119,633
1973	23,010	24,079	7,762	52,891	108,742
1974	6,300 g/	19,116	3,932	54,958	84,306
1975	19,659	23,430	10,703	63,091	116,883
1976	16,198	35,096	25,983	60,719	137,996
1977	10,602	17,214	13,730 h/	40,444 i/	81,990
1978	12,586	24,862	5,903	39,826	83,177
1979	10,398	2,364	2,900	62,120	77,782
1980	9,481	1,156	9,696	37,610	57,943
1981	6,807	20,041	21,025	53,744	101,617
1982	4,913	1,242 j/	23,438	48,431	78,024
1983	15,190	2,262	3,941	42,961	63,922
1984		2,663			
1985		3,900 k/			
Average	16,100	31,608	12,365	68,338	131,731
Average 1979-83	9,358	5,327	12,200	48,973	75,858
Percent of 17-year Average	58	16	99	72	58

a/ 8-hour counts, adjusted for 14-hour counting period (x 1.75).
b/ Counts reconstructed by adjusting actual fish counts to respective run components each week using 1971-82 averages.
c/ Adjusted for missing counts (actual count 61,369).
d/ 21 weeks of missing counts, run not adjusted.
e/ Adjusted for missing counts (actual count 80,934).
f/ Adjusted for missing counts (actual count 52,185).
g/ 6 weeks of missing counts, run not adjusted.
h/ Less 1,625 trapped and transported to tribs downstream form RBDD because of the drought.
i/ Less 20,539 trapped and transported to tribs and hatcheries because of the drought.
j/ Adjusted for missing counts (actual count 405).
k/ Preliminary estimate from Frank Fisher, CDFG, 1985.

Source: California Department of Fish and Game, Anadromous Fish Branch, Red Bluff.

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through early January. Peak spawning occurs in October and November although the timing of runs varies from stream to stream. Incubation occurs from October through March, and juvenile rearing and out-migration of smolts occurs from December through June. Although the majority of young chinook salmon migrate to the ocean during their first few months following emergence, a small number remain in fresh water and migrate as yearlings (Hallock and Fry, 1967). Chinook salmon mature at 3 to 4 years of age although sexually mature 2-year-old males ("jacks") are common. Chinook are the largest Pacific salmon, with mature 4-year fish typically weighing 20 to 40 pounds and occasionally reaching 100 pounds. Age two "jacks" average about three pounds (Hallock and Fry, 1967).

It is probable that the age structure of fall-run salmon is skewed towards younger age classes because of fishing. The ocean troll fishery usually opens in April. Fall-run salmon are subjected to about 4 months of fishing because they do not migrate upriver until late summer or early fall. Elimination of older age classes is a typical result of excessive ocean harvest (Fraidenburg and Lincoln, 1985). In decades past, the dominant age class was probably 4-year-old fish with 5-year old-fish being common. Today, 5-year-old fish are a rarity. Four-year-old fall-run salmon are subject to 2 years of fishing. An increased number of more 4-year-old fish would be expected if fishing pressure is decreased. This occurred in 1985 when tag returns showed a greater proportion of 4-year-old fall-run salmon returning to Upper Sacramento River. The probable cause was thought to be the greater restriction of ocean harvest in 1985 than in previous years.

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Late Fall-Run Salmon

Late fall-run salmon migrate into the Sacramento River from mid-October through mid-April and spawn from January through April. Incubation occurs from January through June and rearing and out-migration of smolts from April through mid-October. Late fall-run salmon overlap during spawning migration with the fall-run from mid-October through December. Prior to 1970, late fall-run salmon were not included in Central Valley spawning stock inventories. For the period 1967-83, however, late fall-run counts at Red Bluff Diversion Dam averaged 16,073 fish, or 12 percent of the total salmon spawning above the diversion dam.

Winter-Run Salmon

Winter-run salmon occur only in the Sacramento River system, with about 98 percent spawning in the main stem of the river (Hallock and Fry, 1967). Winter-run salmon enter the Sacramento River from mid-December through mid-July and spawn primarily in the upper main stem Sacramento River from mid-April to mid-July. The winter-run usually arrives in the Sacramento River near Red Bluff in December and often spends a relatively long holding period in the river before spawning (Hallock and Fry, 1967). Incubation occurs from mid-April through September, with out-migration of smolts beginning in late July and ending in early December.

Historically, winter-run chinook salmon spawned during June and July in the McCloud River. The completion of Shasta and Keswick Dams in the early 1940's blocked access by salmon to this area. Winter-run salmon, however, were able to spawn successfully below Keswick Dam, taking advantage of cooler summer water tempertures afforded by project releases. This run increased dramatically during the 1940's and 1950's, eventually surpassing the spring-run in significance. Unfortunately, total salmon counts at Red Bluff Diverison Dam beginning in 1970 indicate a dramatic decline in winter-run stocks. From a high of 117,808 winter-run spawners in 1969, the population declined to only 1,156 salmon in 1980. Although numbers increaed to 10,000 salmon in 1981, they declined once again to only 1,242 fish in 1982 and 2,663 in 1983. This decline is attributed in part to degraded habitat and warming water temperatures during spawning and incubation periods as a result of greater summer drawdown of Shasta Lake. This was especially evident during the drought years of 1976-77, which resulted in the disasterous returns of 1979 and 1980.

The life history of the winter-run chinook salmon is different from the other three races. The composition of returning adults is more heavily dominated by 2- and 3-year-old fish, and the winter-run production is almost exclusively a function of the strength of the 3-year-old age class. There is a lower percentage of spawners in the successful spawning ages for winter-run. The age structure of winter-run fish is less affected by commercial fishing. Winter-run fish are less susceptible to ocean harvest as they typically migrate out of the ocean, primarily as 3-year olds, during the winter.

In addition to age composition and year class overlap, winter-run chinook salmon have a lower fecundity which decreases their ability to rebound from a catastrophic event. For example, it takes more than three generations for winter-run chinook salmon to rebound from a catastrophic event such as the 1976-77 drought. Winter-run chinook salmon are particularly

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susceptible to adverse water temperature brought on by drought conditions. Based on run counts past Red Bluff Diversion Dam after the drought, it is estimated that it will be 12 years before winter-run chinook salmon return to their pre-drought numbers.

Spring-Run Salmon

Although spring-run salmon were abundant in the Central Valley, only the Sacramento River now supports a significant run. Construction of barriers to migration and higher water temperatures have resulted in the extinction of spring-run chinook in the San Joaquin River system.

Spring-run salmon enter the Sacramento River from late March through September. Many early arriving adults hold in habitats that maintain cool water temperatures through summer before spawning in the fall. Spawning occurs from mid-August through early October, with a peak reached in September. Spring- and fall-run salmon spawning overlap in early October in the main stem Sacramento River. Incubation occurs from mid-August through mid-January with rearing and out-migration of smolts beginning in late November and continuing through April (FWS, 1984).

TEMPERATURE PROBLEMS

The existing conditions in the Upper Sacramento River affect the chinook salmon inhabiting the study area in two principal ways:

1. Water released from Shasta Lake in the spring is usually too cold for rapid growth of fall and late fall-run juvenile salmon. This is important because these fish must attain a certain size (about 70 millimeters fork length) and migrate downstream and smolt before Sacramento-San Joaquin Delta

water temperatures reach 73°F. Smolts cannot survive in the Delta when water temperatures reach 73°F (Kjelson et al, 1983). This typically occurs around mid-June.

2. Water released in August and September is typically too warm for successful spawning and incubation of winter and spring-run eggs and alevins.

Under the existing water demand, the releae of high temperature water during the fall spawning period has not been a serious problem except during years of low precipitation when reservoir storage (Shasta and Clair Engle Lake Reservoirs) was low (1959, 1961, 1964, 1968, 1976, 1977) (Rowell, 1972; USGS, 1976, 1977). Such conditions occurred in 1985. Higher future demands for irrigation and power needs are expected to result in lower reservoir stages and less water of suitable temperature (less than 57°F) to draw upon for fishery needs. Higher anticipated reservoir releases for power and irrigation needs during the spring are expected to result in water temperatures too low for optimum growth, especially just downstream of Keswick Dam. This is especially true during periods when reservoir storage is low (e.g., dry water years and future operation conditions).

Fish maintain a body temperature approximating their environmenta and as such their mortality, growth rates, and distribution are a function of temperature. Salmonids prefer a narrow range of temperatures in which to live (Reiser and Bjornn, 1979). There are defined limits to the preferred range which is a function of acclimation temperature. Although acclimation temperature influences the upper and lower lethal limits and the preferred range, the relative shift in these parameters is still narrow. For example, given equal exposure time, mortality occurs at 80°F and 83°F for juvenile chinook salmon acclimated at 50°F and 68°F, respectively (Brett, 1952).

Temperature is one of the most important environmental variables affecting growth (Moyle and Cech, 1982). Growth rate is maximized around an optimum temperature. Chinook salmon grow the fastest under controlled conditions in 60°F water (Banks et al, 1971). However, this temperature is probably too high for the natural environment because of increased incidences of disease, decreased food items and increased predation (Hughes et al, 1978; Leitritz and Lewis, 1976; Coutant, 1973). The preferred range for juvenile chinook salmon rearing under natural conditions is 45°F to 58°F (Reiser and Bjornn, 1979). The optimum value for juvenile chinook salmon rearing under natural conditions is 54°F, as shown in Table 3 (Reiser and Bjornn, 1979).

TABLE 3
Temperature ranges (°F) and optimum values
for selected stages of the life cycle for chinook salmon

Life Stage	Preferred Range	Optimum
Spawning	42 - 57[a]	
Incubation	43 - 58[a]	
Juvenile rearing	45 - 58[a]	54
Adult migration:[b]		
General	49 - 57.5	
Fall	51 - 67	
Spring	38 - 56	

a/ Reiser and Bjornn, 1979.
b/ Bell, 1984.

As the temperature diverts away from the optimum and approaches the threshold level, growth rate decreases rapidly.

Similar to growth, there are upper and lower temperature limits for successful incubation (Reiser and Bjornn, 1979). The same principle for growth also applies to embryo development, whereby temperature influences rate of development with peak, upper, and lower limits.

The preferred incubation temperature range for Sacramento River chinook salmon eggs and alevins is 43 - 58°F (Healey, 1979). Less than 10 percent cumulative mortality was observed for eggs and alevins incubated in this range. Egg and alevin mortalities increase significantly for temperatures exceeding 58°F with 100 percent mortality occurring at values greater than 62°F (Healey, 1979, Hinze, 1959). An 80-percent loss of eggs and alevins can be expected for an incubation temperature of 61°F. It is evident that the mortality rate for eggs and alevins is very sensitive to slight increases in temperature in the 58 - 62°F range. The lower threshold value for successful egg incubation is 38°F (Hinze, 1959).

In conclusion, spawning by chinook salmon in the Upper Sacramento River occurs during every month of the year. Consequently, optimum temperature conditions for both spawning and rearing cannot occur concurrently. Modification of water temperatures to enhance rearing conditions for one race may adversely affect the spawning and incubation conditions for one or more of the other races.

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FLOW PROBLEMS

Sustained salmon populations in the Sacramento River are dependent upon adequate water quality, food supply, minimal predation, sufficient pool-to-riffle ratios, and a distribution of spawning and rearing habitat that ensures maximum survival. Disruption and changes in the flow regime as a result of development along the Sacramento River have affected all aspects of the chinook salmon's life cycle.

Spawning Habitat Availability

Spawning habitat availability is one of the most important determinants of the size of future salmon populations in the Sacramento River. The quality and quantity of usable spawning habitat is determined by absolute flow, water quality, and condition of spawning gravels. Relationships between flow and usable spawning area were estimated from four riffles in the Upper Sacramento River by Brown (1977). Other investigations into flow-spawning area relationships in the Sacramento system have been carried out by Puckett (1969) on Thomes and Stony Creeks, FWS on the Trinity, Cottonwood and American rivers and Vogel (1982) on Battle Creek. Areas known to have sutiable gravel quality, water depth, and water velocity were tested at different flows. Much of this work parallels instream flow methodologies to arrive at suitability indices. The best available evidence for the Upper Sacramento River shows a maximum usable spawning area available at about 8,000 cfs (Brown, 1977). Flows above 10,000 cfs definitely limit spawning because velocities become too great (Richard Hallock, pers. comm.). Near Anderson, flows of 14,000 cfs were too high for spawning salmon (Burns, 1975). Flows below 6,000 cfs fail to inundate all usable gravels.

Maximum depth of spawning is not as significant as other variables in limiting spawning area. Maximum depths for spawning fall run chinook in Battle Creek were poorly defined deeper than 2 feet but were assumed to occur to 5 feet (Vogel, 1982). Richard Hallock (pers. comm.) has observed winter-run salmon spawning in the main Sacramento River at depths in excess of 12 feet.

Spawning gravels in the Upper Sacramento River were extensively studied (DWR 1980, 1984). Sources, recruitment, bedload transport, sizes and losses of gravel were investigated. Many of the degradations of spawning gravels are directly related to flow. High flows that occur when gravel recruitment has been prevented cause scour and armoring of the riverbed, and stable flows allow fine organic and inorganic particles to lodge between otherwise suitable gravels and produce a matrix unusable for redd construction (bedload cementation). The construction of Shasta Dam eliminated upstream bedload recruitment of gravels. In addition, over 7 million cubic yards of gravel were removed from the river channel for dam construction (DWR, 1980).

Downstream channel modifications (levees and riprap) also reduce available spawning gravels. Flood control activities encourage agricultural expansion onto lands that can only be farmed under the protection of levees. Currently, river meander into gravel terraces is the major source of gravel recruitment for salmon spawning in the Sacramento River (DWR 1980, 1984). Increased riprap and levee construction not only acts to eliminate this source of gravel but concentrates flows in the main part of the channel, thereby increasing stream velocity, gravel transport, scour, and armoring.

Rearing Habitat Availability

Optimum substrate for rearing appears to be gravels smaller than those used for spawning (Schaffter, DFG, pers. comm. 1983), but substrate appears to be less important than water depth and velocity (Bovee, 1978). In addition, food supply distribution does not appear to limit chinook fry distribution in the Upper Sacramento River.

Flow regimes for optimum rearing maximize the area and distribution of preferred habitats. Specific data describing these flows have not been developed for the Sacramento River.

Winter flows occasionally reaching 30,000 cfs at Sacramento may optimize smolt survival in the lower Sacramento River in April, May, and June. There is a direct correlation between high flows from October through February and a high number of outmigrants in the estuary, as in 1982 and 1983 (Tom Richardson, FWS, pers. comm.). In 1984, most rearing occurred in the Upper Sacramento River because of low, clear flows in the spring. Fry use the estuary as a nursery area when winter flows are high, but only use the upper river when winter flows are low, as in 1984. Winter storm surges from the upper river may be important in redistributing rearing salmon to make better use of estuarine rearing areas (Tom Richardson, FWS, pers. comm., 1983).

Fish Passage

Adequate flows for adult chinook passage are usually present in Central Valley rivers (Fry, 1965). However, radio-tagging of adult chinook at Red

Bluff Diversion Dam indicated that delays and partial blockage during high flows may be a problem there (Hallock, Vogel, and Reisenbichler, 1982). Delays ranged from 4 to 18 days for all four runs and only 63 percent of all radio-tagged salmon could be accounted for passing the dam. Winter-run salmon were delayed the longest, and the most severely blocked. Under current operations, high flows at Red Bluff, especially over 10,000 cfs, appear to delay and partially block adult chinook salmon.

With high flows and current operation of Red Bluff Diversion Dam, salmon have difficulty finding the fishways and moving upstream to spawn. Above the dam there is sufficient spawning habitat to accommodate many more fish (John Hayes, DFG, pers. comm.). Blockage or substantial delay of migration results in reduction of successful spawning and recruitment. The late-fall and winter chinook runs depend on the river above Red Bluff for most of their spawning. The FWS found during March and April of 1981 that 92 percent of the fish passed through the fishways at Red Bluff Diversion Dam when flows were less than 10,000 cfs. January through May is the period when high flows through the diversion dam generally cause the most substantial delays.

Pollution

The most critical pollution problem in the upper Sacramento River is the drainage of acid mine waste from abandoned mines near Spring Creek above Keswick Dam (Finlayson and Verrus, 1980). This pollution has killed adult and juvenile salmon and other aquatic life periodically for over 70 years. The construction of Shasta Dam reduced natural flows which diluted the acid mine waste. The dam also blocks salmon from their historical spawning area in unpolluted streams above the dam. The DFG and BOR have developed flow-dilution criteria which reduce salmon losses. A combination of source control and water management and is the most promising long-term solution. This subject is analyzed in problem C-1 of the Central Valley Fish and Wildlife Management Study.

Food Supply

River velocities determine the distribution of feeding areas for juvenile chinook, with higher velocities often displacing fish from their preferred feeding areas. High flows appear to act most importantly on food supply by increasing turbidity and silt load which in turn can reduce the ability of young salmon to feed. Short-term high winter flows are important, however, in maintaining food supplies for production of fall-run salmon which rear in the estuary (Rose, 1980).

Predation

Most predation of young salmon in the Sacramento River system takes place at diversions and fish screens (Schaffter, 1978; Hall 1979, 1980a, 1980b), and at juvenile fish release sites (Pickard, Grover, and Hall, 1982). Sacramento squawfish are the major predator at Red Bluff Diversion Dam (Hall, 1977; Vonderacek and Moyle, 1982). When young salmon are artificially concentrated, stressed, or disoriented, they are more vulnerable to predation than they are in natural systems (Brown and Moyle, 1981; BOR, 1983). Hatchery releases of salmon near diversions, flow shears and structures, flood lights, or in high water temperatures contribute to increased predation. Riprap and levee material with large interstices favor predation by black basses and sunfishes by providing ambush locations. Higher river flows, turbidity, and dispersal of downstream migrant salmon act to reduce predation.

Diversions and Entrainment

Major diversions on the Upper Sacramento River include the Anderson-Cottonwood Irrigation District diversion dam at Redding, the Tehama-Colusa Canal and Corning Canal at Red Bluff, and Glenn-Colusa Irrigation District diverison near Hamilton City. Each of these diversions has devices which provide some protection for juvenile salmon (Quelvog, 1981), but there are over 900 virtually unscreened diversions on the Sacramento River between Keswick Dam and the estuary (Hallock and Van Woert, 1959). All of these diversions, both screened and unscreened, are sources of mortality for migrating or rearing juveniles. Primarily young fish are lost at unscreened diversions. These fish migrate near the surface and thus are more susceptible to surface than to pump diversions. Mortality at screened diversions is primarily caused by impingement, and predation (Decoto, 1978; Hall, 1979; FWS, 1980).

Flow Fluctuations

Temporary flow surges and accompanying turbidity stimulate juveniles to migrate downstream, redistribute accumulated nutrients and silt deposits, loosen up gravels for future spawning, and provide cover from predators that feed most efficiently in clear water. Conversely, even temporary flow reductions produce many negative effects. Spawning is disrupted as the water velocity and depth are suddenly reduced. Viable eggs already deposited are exposed to the atmosphere and die. Alevins in the gravel can be killed by dewatering, elevated water temperature, or depressed oxygen levels.

Dewatering as brief as 1 hour is much more detrimental to alevins than eggs in any stage (Becker, Neitzel, and Ficheisen, 1982). Fry and fingerlings stranded in pools and side channels can be lost to many sources such as those described above. The total magnitude of losses from abrupt flow reductions to fish of this size depends primarily upon the frequency of occurrence. The size of losses to eggs and alevins are more directly related to the numbers of redds exposed by dewatering, rather than the frequency of occurrence.

An abrupt flow reduction in the Upper Sacramento River is caused by the spring installation and fall removal of flashboards for the Anderson-Cottonwood Irrigation District dam at Redding. The procedure usually lasts a few days, and follows BOR policy which limits flow reductions from Keswick Dam to no more than 15 percent of the initial flow per 12 hours, or 2.5 percent of the initial flow per hour, unless emergency public safety measures require more rapid changes. These metered flow reductions are designed to lessen detrimental impacts on salmon. The operation and impacts of the Anderson-Cottonwood Irrigation District dam are discussed in detail in the BOR report (1983).

A major change brought about by the construction of Shasta Dam and Trinity River diversion was the increase of the mean December discharge at Keswick Dam to 150 percent of pre-Shasta flows. While January and December flows have been near pre-Shasta levels, summer and fall discharges at Keswick are now nearly 4 times higher, as shown on Figure 4.

These long-term, excessive flows have blocked and delayed the migration of adult salmon at Red Bluff Diversion Dam, buried redds by moving gravel, and displaced juvenile salmon due to the high water velocity. Furthermore, potential suitable spawning areas are scoured away by excessive water velocity. This action can over-crowd spawners onto the remaining suitable

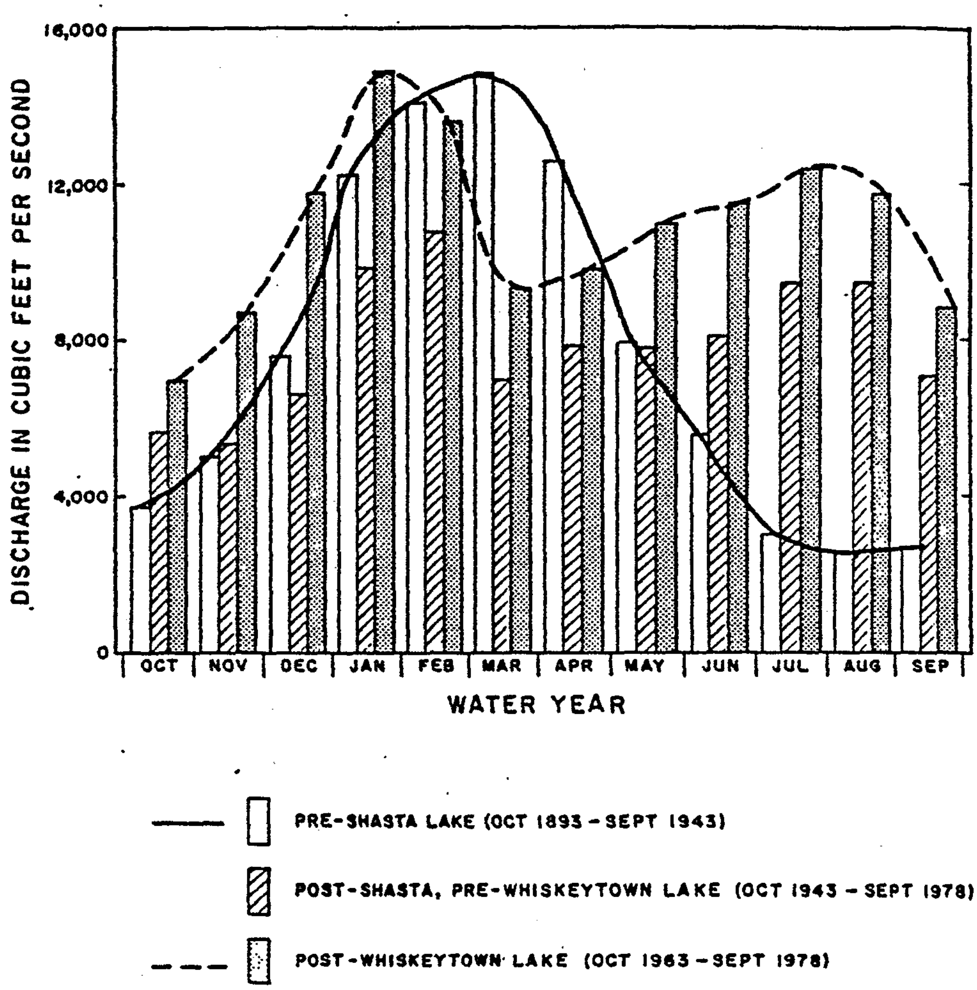

FIGURE 4.
Mean monthly discharge in the Sacramento River at Keswick California.
(Table from California Department of Water Resources, 1980)

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gravels, which in turn can cause spawners to excavate the redds of previous spawners thereby reducing total productions (Painter, 1977).

Turbidity usually increases with high flows. Prolonged periods of high turbid flows severely impact spawning, early development, and rearing, as well as causing premature downstream migration of juveniles. Under certain conditions, such as occurred in the spring of 1974, the Trinity River diversion increases baseline turbidity for extended periods. Prolonged high flows carry silt loads capable of burying spawning gravels, decreasing the ability of juveniles to feed, and reducing invertebrate populations which are the main food source for juveniles.

Three weeks of flow at 36,000 cfs or greater between November 1979 and June 1980 scoured out 98 percent of the suitable spawning gravel at Redding riffle (DWR, 1980). Since the construction of Shasta Dam, at least 49 months had mean flows in excess of 20,000 cfs and at least 12 storm peaks exceeded 50,000 cfs at the Keswick gauge.

PRESENT STATUS OF CHINOOK SALMON RESOURCE IN THE SACRAMENTO RIVER

Salmon spawning escapement in the Sacramento River has declined significantly in recent years, as indicated on Table 4 and Figure 5, which show the spawning stock estimates for the fall run between 1939 and 1983. Fall-run counts were used because they are more accurate, available for a longer period, and easier to estimate than the other runs or the total run.

No actual counts are available before 1937; counts between 1937 and 1943 are incomplete at Redding; 1943 to 1966 counts are based on tag recoveries and

TABLE 4

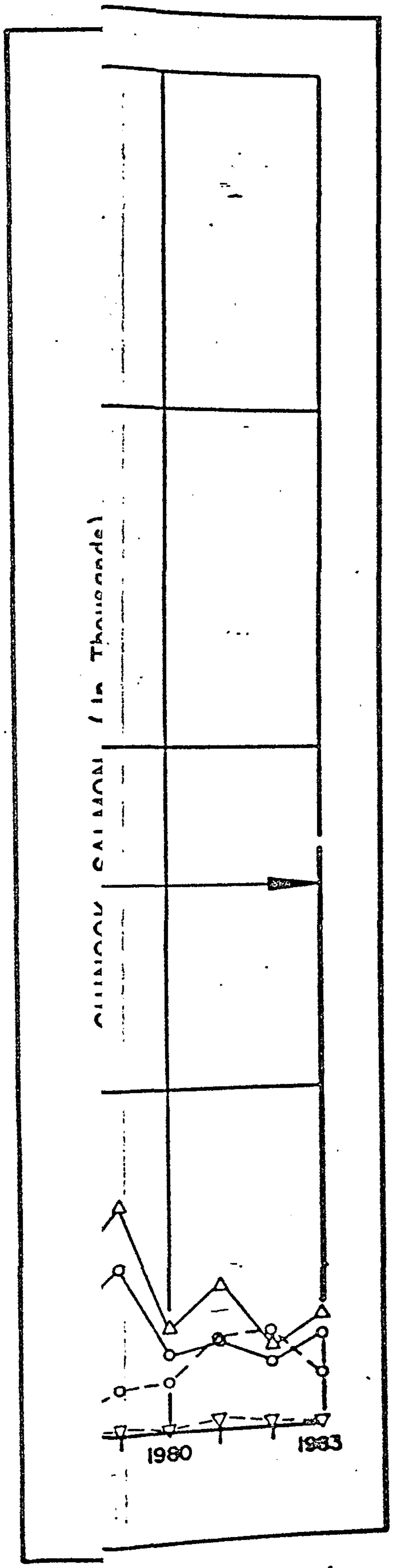
CHINOOK SALMON SPAWNING ESTIMATES (IN THOUSANDS)

Date	Sacramento River Above Red Bluff	Tributaries Above Red Bluff	Sacramento River System Above Red Bluff	Sacramento River Below Red Bluff	Tributaries Below Red Bluff
1937	8*	-	8*	-	-
1938	14*	-	14*	-	-
1939	16*	-	16*	-	-
1940	29*	4	33*	-	-
1941	30*	3	33*	-	-
1942	4*	3	7*	-	-
1943	36*	2	38*	-	-
1944	73*	3	76*	-	-
1945	52*	3	55*	-	-
1946	49	17	66	-	-
1947	75	16	91	-	10
1948	40	4	44	-	5
1949	50	8	58	-	2
1950	111	4	115	-	2
1951	73	14	87	-	12
1952	267	15	282	-	28
1953	408	24	432	-	18
1954	276	21	297	-	11
1955	231	28	259	-	4
1956	87	29	116	6	1
1957	55	7	62	12	8
1958	107	35	142	21	6
1959	257	36	293	9	1
1960	219	26	245	14	2
1961	140	21	161	9	2
1962	130	26	156	9	6
1963	139	31	170	7	3
1964	143	23	166	5	1
1965	105	14	119	2	0
1966	112	15	127	3	1
1967	78	7	85	9	1
1968	98	24	122	12	1
1969	135	19	154	18	3
1970	65	12	77	6	5
1971	59	5	64	23	2
1972	36	5	41	16	1
1973	44	8	52	18	2
1974	49	4	53	28	2
1975	52	5	57	36	2
1976	48	9	57	37	1
1977	39	3	42	46	2
1978	34	5	39	48	0
1979	48	13	61	67	2
1980	22	14	36	30	1
1981	26	27	53	43	3
1982	19	28	47	24	2
1983	27	15	42	33	1

Source: "King Salmon Spawning Stocks of California's Central Valley" CDFG annual reports and unpublished data from Frank Fisher - CDFG, Red Bluff.

* Incomplete counts
\- No counts

Figure 5



LEGEND

•••o——o— Spawning Stock in upper Sacramento River above indicated sample point. Dotted line indicates low estimates or incomplete counts.

–o– – –o– Spawning Stock in tributaries above Red Bluff.

—△——△— Spawning Stock in Sacramento River below Red Bluff.

–▽– –▽– Spawning Stock in tributaries below Red Bluff.

Note: Spawning Stock estimates are for fall run chinook salmon above the Feather River.

SOURCE:

"King Salmon Spawning Stocks of the California Central Valley, 1940–1950" (Fry, 1961)

"King Salmon Spawning Stocks of the California's Central Valley" (CDFG Annual reports)

personal communication (Frank Fisher, CDFG)

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

MIDDLE SACRAMENTO RIVER
SPAWNING GRAVEL STUDY

FALL RUN SPAWNING STOCK ESTIMATES

1984

spawning area surveys; and 1967 to present counts include counts from Red Bluff Diversion Dam.

There is a noticeable shift in the estimated number of fall-run chinook salmon spawning in the mainstem Sacramento River between Keswick Dam and Ord Ferry as shown in Table 5. The shift occurred in 1966 and is presumably due to the closure of the Red Bluff Diversion Dam. More than 90 percent of the mainstem spawning fall-run chinook salmon spawned in the Upper Sacramento River above the dam prior to 1966. This has dropped to less than 50 percent in recent years.

In addition, before the construction of Shasta Dam, it was estimated that about 27,000 salmon spawned above Keswick Dam (U.S. Department of the Interior, 1940) and an unknown number spawned below. Incomplete counts between Keswick Dam and Battle Creek indicated a spawning population in excess of 50,000. Counts from 1950-59 averaged 190,000, with a high of 408,000 in 1953 and a low of 68,000 in 1957. The DFG believes the 190,000 to be a more accurate estimate of the annual spawning population in this reach.

The estimated mean annual spawning population dropped to 130,000 for the period 1960-69, even though the river reach within which salmon were counted was extended down river to Red Bluff. The estimated mean for the period 1970-79 dropped sharply to 48,000, and the decline continued from 1980-84, with a 4-year estimated annual mean count of only 24,000. Although it is normal for salmon escapement to vary from year to year, it is clear that the spawning population of the Sacramento River mainstem above Red Bluff has declined to about 13 percent of the 1950-59 estimated level.

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Formulation of Alternative Plans

Structural

The 1976 water year, classified as a dry year, was the critical year for the strucutral analyses because of its effect on the fishery resources. It was also the year that the temperature control structure could have a significant impact. Water released into the Sacramento River from Keswick Dam should not approach critical temperature levels during wet and normal years. For these two representative water years (1976, 1977), there should be sufficient water available in reservoir storage to buffer the transfer of heat to the lower levels of Shasta Lake. On the other hand, there was little that could be done to control water temperatures for the critically dry year illustrated by 1977. Reservoirs would not fill and would drop to low levels very early during a 1977 type water year. Thus, the water would be warm early in the year and would get warmer as the lake levels dropped.

Nonstructural

Hydrologic and power operations studies of the CVP were completed for the four fishery flow alternatives and a base or existing flow condition. The operations studies cover 76 years of hydrologic record (1895-1970) and include 1980 and 2020 level demands.

Because the temperature models require daily data input, an analysis of all 76 years was well beyhond the scope of this study. To cover a range of hydrologic conditions, therefore, 5 years were selected for the temperature analysis: 1923 (dry), 1931 (critical), 1934 (critical), 1954 (normal), and 1958 (wet). These specific years were chosen because they had similar Shasta inflows to the years 1977, 1976, 1975, and 1974, respectively, which were evaluated in the Shasta temperature control studies. This facilitated input file development since daily inflows and inflow temperatures to Shasta Lake were alredy available for 1974-77. Climatological data and Sacramento River tributary inflow data for these years were also applied to the five flow study years.

Input file parameters that were modified to reflect the flow study years included initial Shasta storage, Shasta release, and Whiskeytown diversion to Keswick Reservoir.

STRUCTURAL ALTERNATIVES

Alternative 1 - Diversion Tunnel Modification

As shown on Figure 6, this concept uses the existing diversion and old Southern Pacific Railroad tunnel. Reservoir water would enter the horseshoe shaped conduit at a centerline elevation of approximately 651 feet and flow 1,364 feet to a bifurcation. This bifurcation would begin the new construction as the flow was diverted about 60 degrees to a 20-foot irrigation district concrete-lined tunnel. Flow would proceed through this new tunnel for 108 feet to a 20-foot diameter penstock which would feed turbines 1, 2, and 3. There is one high pressure 16-foot-square fixed wheel gate upstream of the first bifurcation and one 15-foot fixed wheel gate for each of the three penstocks fed. In this way, flow to any one generator could be shut off. A 5-foot diameter fixed cone valve is located at the end of the existing tunnel about 538 feet downstream of the bifurcation.

Additional grouting under the dam and around the tunnel may be

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would be the same as at the present except during the spawning season. At the beginning of the spawning season, the coaster gates would be lowered on penstocks 1 through 3 and the gates on the new penstocks would be opened. Maintenance on the fixed wheel gates used for control of the new penstocks would be minimal.

Alternative 2 - Multilevel Withdrawal Structure and Diversion Tunnel

This alternative consists of a combination of the preceding Alternative 1, the diversion tunnel, and Alterantive 3, the multilevel withdrawl structure. Operation and maintenance of this alternative would be a combination of operations and maintenance for Alternatives 1 and 3.

Alternative 3 - Multilevel Withdrawal Structure

As shown on Figure 7, Alternative 3 is patterned after the Flaming Gorge design built in 1977. This design would consist of a tubular steel framed structure covering all five penstock 1050 to their bottom. The structure itself would be covered on five sides by corrugated metal. The weight is supported by cables running from the tubular frame to anchors affixed to the upstream dam face near the crest. The structure would be firmly in place against the face by bolts secured into drilled holes on the face.

Water would enter the structure's interior and thus the penstocks through a combination of pivotal (louver type) shutter and slide gates. Five semi-circular shutters, located at elevations 902, 942, 975, 1000, and 1050, would open to intake an area of 600 square feet each. These shutters would rest atop the structure and inside the trashracks. Four (15′ x 40′) rectangular shutters at elevations 733, 746, 767, and 815 would open to an intake area of

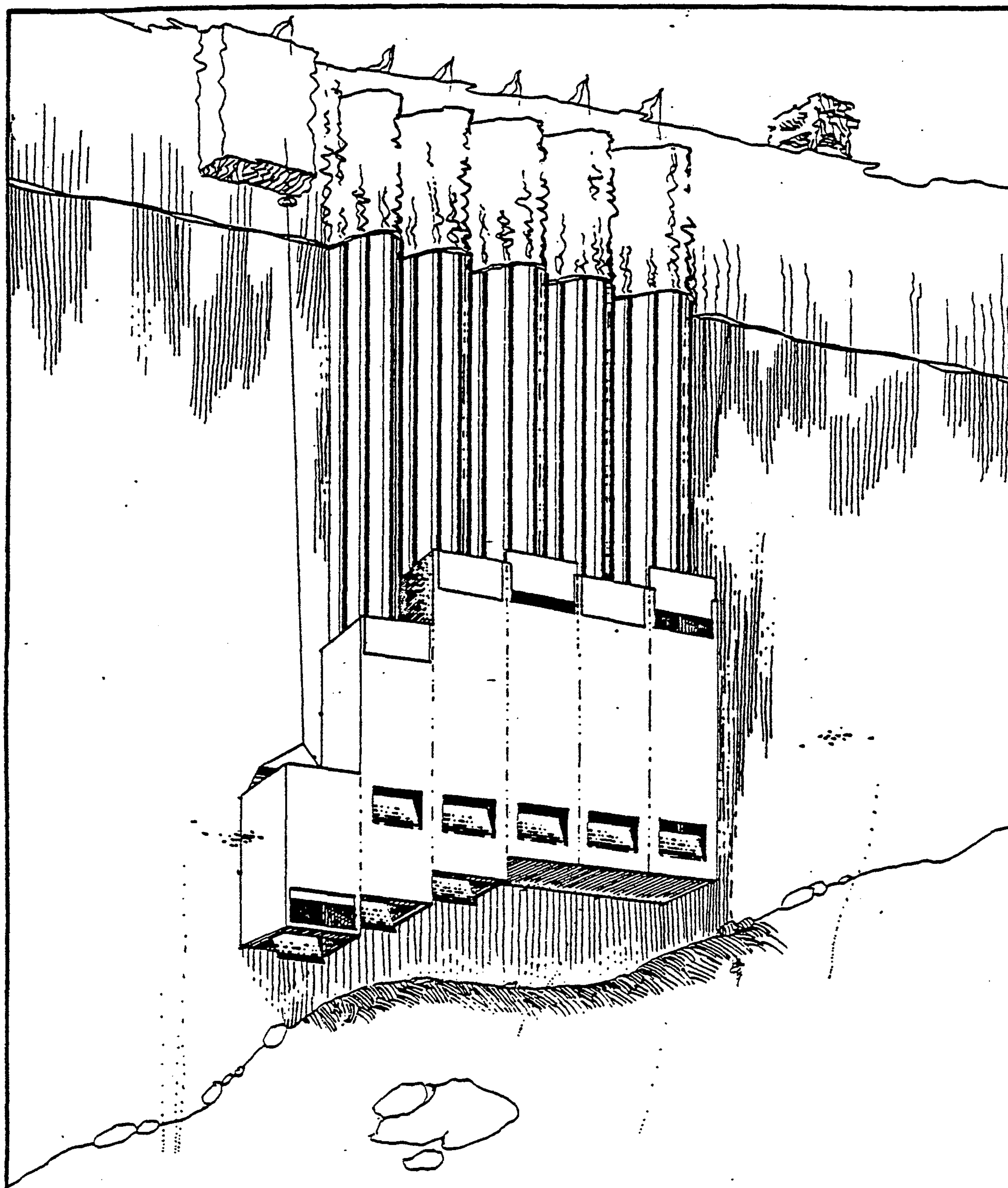

FIGURE 7.
Alternative 3: Multilevel Withdrawal Structure

Alternatives to the base condition are identified as alternatives 1 through 4 and are defined on Table 7.

TABLE 7
Sacramento River Minimum Flow at Keswick
Alternatives 1-4, BOR Model Studies

Alternative	Period	Hydrologic Water Type Year Wet or Normal	 Dry (cfs)	 Critical
1	January-December	6,000	6,000	4,500
2	January-December	6,000	4,500	4,500
3	January-December	6,000	4,500	Base
4	January-December	6,000	Base	Base

COMBINATION ALTERNATIVE

In addition to the structural and nonstructural alternatives, a combination of these alternatives was developed and analyzed. The model studies combined the structural alternatives (diversion tunnel combination and multilevel withdrawal structure) with the four flow alternatives. (The base condition is the same in both the structural and nonstructural analysis.)

FUTURE WITHOUT CONDITIONS

Water deliveries from existing CVP facilities for the year 2020 would increase, resulting in reservoir water levels being lowered more rapidly and to a greater extent than present. Currently, during wet and normal water years, reservoirs fill to capacity and remain relatively high into the fall. In addition, the excess water is used for other purposes such as

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hydropower production. If necessary, water is spilled in the fall to drain the reservoirs down to flood pool elevation by December. In the future, there will be a lower frequency of fill and spill conditions, and higher water temperatures will result from the lower pool elevations. Potential impacts to fish in a critically dry year are shown in Table 8.

TABLE 8
Potential Temperature Impacts of
Proposed Action/Future Without in a Critically Dry Year (1933)
(estimated mean monthly temperatures in degrees Fahrenheit)

Location and criteria	1980 Level of Development							2020 Level of Development						
	May	Jun	Jul	Aug	Sep	Oct	Nov	May	Jun	Jul	Aug	Sep	Oct	Nov
Sacramento River at Keswick														
Proposed action	47	49	53	56	58	57	54	48	52	59	62	62	59	56
Future without	47	48	52	55	57	56	54	47	50	55	58	60	58	56
Increase with proposed action	0	1	1	1	1	1	0	1	2	4	4	2	1	0
Sacramento River at Cottonwood														
Proposed action	51	53	59	60	60	57	53	53	56	62	63	63	59	55
Future without	51	53	58	59	59	57	53	53	55	59	61	61	58	55
Increase with proposed action	0	0	1	1	1	0	0	0	1	2	2	1	1	0
Sacramento River at Red Bluff														
Proposed action	53	55	61	61	61	57	52	55	57	64	64	63	59	54
Future without	53	55	60	60	60	57	52	55	56	62	62	62	58	54
Increase with proposed action	0	0	1	1	1	0	0	0	1	2	2	1	1	0

Water temperatures in the Upper Sacramento River would become lethal for salmon with the proposed 2020 operations. Total mortality for chinook salmon eggs and alevins would be 100 percent during August and September at Keswick used in the ecomomic analysis to derive a cost-effectiveness comparison for both the structural and non-structural alternatives.

DESCRIPTION OF TEMPERATURE MODEL

The temperature model consists of three separate but interrelated models: a reservoir temperature model, a river temperature model, and a temperature-related salmon mortality model. Output from the reservoir model becomes input to the river model, and output from the river model is input to the mortality model.

To cover a range of hydrologic conditions, the model studies evaluated four different years (1974, 1975, 1976, and 1977); 1974 was an extremely wet year, 1975 above normal, 1976 a dry year, and 1977 an extremely dry year. Based on 76 years (1906-81) of unimpaired flows on the Sacramento River near Red Bluff, the 4 study years were wetter than approximately 99 percent, 63 percent, 12 percent, and 3 percent of the years of record, respectively.

For each of the 4 years, the models were used to simulate operation of the existing Shasta Dam outlet structure (historical condition) and the three structural modification alternatives (diversion tunnel only, diversion tunnel and multilevel withdrawal structure, and the multilevel withdrawal structure only). The model results compare the temperature control and salmon benefits obtained from the three structural alternatives.

Reservoir Model

The reservoir model used to simulate Shasta Reservoir temperatures was the Water Quality for River-Reservoir Systems (WQRRS) model developed by the Corps of Engineers (Smith 1978). The September 1984 updated version of the

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model was used. The input data preparation, verification, and preliminary simulation runs were performed by BOR's Denver Engineering and Research Center (George 1980). More recent simulations were completed in the BOR's Sacramento Regional Office.

The WQRRS model represents the reservoir as a series of one-dimensional horizontal slices, and the water is assumed to be fully mixed with all isotherms parallel to the water surface. Tributaries and dam releases occur as sources or sinks within each year. The internal transport of heat and mass within the reservoir occurs only in the vertical direction. The transport occurs by advection and through an effective diffusion mechanism that combines the effects of molecular and turbulent diffusion and advective mixing.

The movement of water, or the advective effect, is governed by the location of inflow to and outflow from the reservoir. The inflow to the reservoir came from three main tributaries: Sacramento River, McCloud River, and Pit River. Data supplied by the USGS were used to determine the tributary flows and temperatures on a daily basis for the years 1974, 1975, 1976, and 1977. Based upon the tributary temperature, a density was computed. The tributary inflow was allocated to the particualr horizontal reservoir layer that had the same density as the tributary water. If the inflow water density was outside the range of density found within the reservoir, the inflow was deposited either at the surface or at the bottom depending on whether the inflow water density was less than the minimum, or greater than the maximum.

The reservoir releases for the same years were provided by the Regional Office in Sacramento. To maintain a reservoir balance based on computed inflows, the tributary flows were adjusted using the same proportionalities

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determined for each outlet release by computing the vertical limits of withdrawal and allocating the flows accordingly. Daily releases and temperatures computed from the reservoir model were used as direct input to the river model.

River Model

The river model was developed by the BOR's Engineering and Research Center. It is similar to the steady-state model used for Green River below Flaming Gorge Dam in Utah (Sartoris 1976). Modifications of the Green River model were made for application to the Sacramento River.

The river model simulates approximately 65 miles of the Sacramento River from Shasta Dam to Red Bluff, California. Five major tributaries enter the Sacramento River between Shasta Dam and Red Bluff. The discharges and the temperatures for Spring Creek, Clear Creek, Cow Creek, Cottonwood Creek, and Battle Creek were obtained from the USGS on a daily basis for the 4 years simulated. Temperature records for Cow Creek and Battle were incomplete; therefore, some of the data were synthesized. A linear correlation was developed for the temperatures at Cow Creek based on the temperatures at Clear Creek. The recorded temperatures for Battle Creek were virtually nonexistent. Because Battle Creek and Cottonwood Creek were similar in drainage area and both tributaries entered the Sacramento River at the same point, it was assumed that the Battle Creek water temperature would be the same as that of Cottonwood Creek.

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Equilibrium temperatures were computed on a daily basis on the following meteorological data: (1) dry bulb temperature, (2) wet bulb temperature, (3) barometric pressure, (4) cloud cover, and (5) windspeed.

The equilibrum temperature is highly dependent upon ambient air temperature and windspeed. In the winter months, the equilibrium temperatures were lower than the released water temperatures from Shasta Dam; therefore, the water would typically cool down. This is due to the ability of the reservoir to store some heat from summer months at lower elevations during the winter. In the summer months, the equilibrium temperatures were higher than the typical water temperatures released from Shasta Dam; therefore, the water would warm up. The formulation of the net exchange equation based on the equilibrium temperature can be found in reports by Edinger and Geyer (1965).

The river model operates by routing a slug of water downstream. When a tributary enters the Sacramento River, the discharge is increased accordingly and the water temperature is increased or decreased proportionally based on the assumption of complete mixing. The water temperature at any point along the Sacramento River is based on a temperature of the upstream reach, the tributary temperature, and the net heat exchange that has taken place between the water and the atmosphere in the intervening time and distance. Travel time and distance are computed from the water velocity within a particular reach.

The DWR's Bulletin No. 111, State of California was used to obtain the hydraulic characteristics of the Sacramento River at given discharges for the years 1960-61. A statistical analysis program showed that a quadratic relationship between cross sectional area and discharge was the best for the range of flows provided. Also, a quadratic relationship was established for

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downstream temperatures. Although not entirely true, this assumption is acceptable for two reasons, first, river temperatures tend to approach ambient levels by the time the water reaches Red Bluff. Thus, temperature changes at Keswick are dampened significantly by the effects of air temperature and other meteorological conditions prior to reaching Red Bluff. Second, salmon benefits (i.e., mortality reductions) in the reaches downstream of Red Bluff computed for the various alternatives will tend to be conservative (i.e.,overestimated). This occurs because temperature changes at Red Bluff will dampen in the downstream direction due to climatic effects rather than remain constant as assumed by the model. Therefore, beneficial decreases in summer temperatures and increases in winter temperatures below Red Bluff will be overestimated.

Verification of the mortality model was not possible. The accuracy of the predictions depend on the accuracy of the river temperature simulations as well as the various fishery assumptions that are part of the model. While the accuracy of specific estimates may be questionable, the model is a valid tool for comparative purposes since the assumptions and methodology were the same for all conditions evaluated.

DESCRIPTION OF OPERATIONS STUDIES

The structural alternatives assume no change in the existing operations of facilities, i.e., base case. The nonstructural alternatives assume operation changes previously described under the four flow alternatives. Again, the base case assumes no change in the operation of existing facilities

DESCRIPTION OF RESERVOIR STUDIES

The impacts to reservoir fishery as a result of alternative operations schedules apply only to the nonstructural alternatives. For these alternatives operations schedules developed for selected water years representing all years of record (1922-1970) with dry (1923), critical (1931 and 1934), normal (1954) and wet (1958) were analyzed. Data on 1980 and 2020 levels of water developement were used in identifying the impacts to reservoir fisheries under the various nonstructural altenratives.

Standing Crop

The equation below developed by the FWS Reservoir Research Program (FWS, 1981) for reservoirs greater than 500 acres in area at normal pool was used to calculate total standing crop (in pounds per acre).

BC 1A

log (total standing crop) = 2.105 + 0.666 log (TDS/mean depth) - 0.223 [log (TDS/mean depth)]2

N = 50   R2 = 0.72   Prob > F = 0.0001

Total dissolved solids and mean depth were the two variables which determiend standing crop values. Mean total annual standing crop values were determined for 49 years of record (1922-1970) and for selected years (Table 5, Appendix E). Differences in standing crop values within each year for each alternative operation schedule and standing crop values between alternatives for 1980 and 2020 levels of development were compared for each reservoir. For example, in Clair Engle Lake for the year 1923, standing crop values under each alternative operation schedule in the 1980 and 2020 levels of development were compared. Mean standing crop values were then compared for all years under the historical data, greater power losses would be calculated.

The value of the lost power was calculated using the Federal Energy Regulatory Commission fuel escalation methodology. It was assumed the lost power would have displaced oil-fired generation within the Northern California power system, specifically Pacific Gas and Electric (PG&E) service area. The real fuel escalation rates provided to the California Energy Commission in PG&E's Common Forecasting Methodology V were used in the analysis.

The value of power is a combination of capacity value and energy value. Capacity is a measure of the power available to meet peak loads. Energy is a function of power over time. Power values were determined by escalating present Federal Energy Regulatory Commission values over the first 30 years of a 100-year period of analysis. Calculations were based on the following data:

Interest rate	= 8-5/8 percent
Fuel price base	= 1982
Project on line date	= 1992
Period of analysis	= 100 years
Escalation period	= 30 years

The present worth value of capacity was calculated to be $16.5 megawatt hours (MWh). The present worth value of energy is $98.5 MWh. Therefore, the total value of power is $115 MWh. Based on these dollar figures, the value of lost power was determined.

Nonstructural

The power benefit calculations were based on a comparison of a base case operation (existing flow conditions) to four proposed nonstructural alternatives. For the base case and the proposed alternatives, a short-term study to determine project dependable capacity and a long-term study to determine average annual generation were performed. Studies were done at the 1980 and 2020 levels of development.

Impacts to power benefits were determined by assuming 1980 level studies would be representative of the project on-line operation for 1990 and that any change to power benefits would be linear to 2020 and then remain constant. These benefits were then annualized over a 100-year period at 8-5/8 percent interest.

DESCRIPTION OF ECONOMIC ANALYSIS

Structural and Nonstructural

The economic analysis presented in this report does not follow the conventional procedure wherein estimated direct project benefits and costs are compared in order to determine the economic justification of a proposal, that is, do direct economic benefits exceed implementation costs. Accomplishments for the alternative plans evaluated have been estimated by computer model in terms of the reduction in annual chinook salmon spawner mortality in the Upper Sacramento River. The decrease in spawner mortality would be expected to lead to increased numbers of salmon in the river and migrants to the Pacific Ocean. Sport fishing activity --river and ocean--and ocean commercial fishing should increase accordingly.

LIMITATIONS OF STRUCTURAL AND NONSTRUCTURAL ANALYSIS

Quantification of Fishery Impacts

All non-structural (flow) scenario evaluations indicated that salmon would be adversely impacted even though the scenarios allowed for increased flows over the base condition. The increased flows were intended to benefit

It is anticipated that 2020 reservoir storage, flow releases, and operations will cause low reservoir storage levels to occur as they do in the dry year conditions. This will become the norm rather than the exception. With winter-run salmon being the weak link and very susceptible to these conditions, Alternative 2 provides the most benefit to this run.

Model Limitations of Temperature Mortality Model

Results for the spring-run salmon are not factored in due to the problems in the model that could not be corrected. The problems with the results regarding the spring-run are that the simulated temperatures for the alternatives are always less beneficial to salmon than the historical temperatures but that this is shown to be deleterious to that race. It does not make sense that when temperatures are near the upper tolerance limit cooler water temperatures are worse for the fish.

The temperature model uses average historical monthly temperatures and predicted average monthly temperature for each alternative. Obviously, an average value represents an intermediate value because it is calculated from values that are higher and lower. An average value could mask temperature fluctuations that could be deleterious to the salmon. There can be both diurnal and monthly fluctuations. Initially, the average daily temperature could be below the critical level but by the end of the month, it could be above it. The average monthly value calculated from taht data could be below the critical level but most the years spawn could have been wiped out by the high temperatures at the end of the month. Short periods of high temperatures, such as in the afternoon, may not be as significant a problem as

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chronic high temperature. Future analyses could use average high temperatures. This results in a conservative estimate of benefits because it maximizes temperature induced mortalities.

Limitations in Economic Analyses.

The values developed for both accomplishments in terms of reduced fish mortality and the associated reduction in power output at Shasta were based on just 4 hydrologic years. Some degree of uncertainty must attach to any results based on such a small sample though the historic years used in the analysis represented a wide range of hydrologic conditions. Increasing the number of observations would increse the confidence in the results.

Limitations of Operations Studies.

Consecutive hydrologic years were used as the bsis of the analysis. Hydrologic conditions in one year can affect reservoir operations in succeeding years in terms of the ability to release cold water to reduce fish mortality and to generate power. Spawning in a give year is influenced by cklimatic conditions and reservoir operations occurring 3 to 4 years prior. The computer model predicted fish mortality for a selected 4-year period and the ability to generalize from these results to the long term depends critically on the representativeness of the selected period. In this case, two of the years, 1976 and 1977, were the two driest consecutive years on record. The probability of their recurrence must be considered small and generalizing from them is risky. The depleted reservoir condition going into 1977 would lessen management flexibility and limit the options available for reducing fish mortality. A stochastic hydrology could eliminate the effects of this interdependence.

5. Historical before October 15, then through elevation 650 feet for rest of year.
6. Surface releases (842 feet or 942 feet) before October 15, then through elevation 742 feet for rest of year.

The historical temperatures simulated for Bend Bridge were compared to the USGS measured temperatures (Figures 2, 5, 8, 11). The river model is sensitive to rapid changes in the ambient air temperature and windspeed. As a result, some of the model results were above or below the measured values. However, the modeled temperatures were generally within 1.0 to 2.0 C of the measured values, which is good for this type of model.

Shifting to lower level releases in June reduced summer temperaturs (June-September), but increased fall temperatures (October-November) in some instances (Figures 7-12). The 650 feet releases, while cooler in the summer, were warmer than either the historical or 742-feet releases in the fall. This occurred because all of the cold water was removed from the reservoir at elevation 650 by October and replaced by warmer water, resulting in warmer fall releases.

This paradox also occurred in the operations that shifted to the low level outlet in October (Figures 13-21). The 650 feet releases had higher temperatures than the 742 feet release because the volume below elevation 650 was smaller than the volume released. This resulted in a downward shift in the temperature profile causing warmer releases.

In 1977 (Figures 19-21), surface releases were cooler in late summer and fall than other operations because the thermocline was shifted upward. This caused 2 to 3 C cooler temperatures at Clear Creek compared to historic operations. The temperature reduction dampened to less than 1 C at Bend Bridge and Red Bluff due to meteorological impacts.

Mortality Model. The mortality model was used to quantify and compare temperature impacts to Sacramento River salmon for the alternatives considered. Results of the model runs are shown in Tables 1-___of Appendix C. Although the mortality model computes salmon losses on a daily basis, the results are presented as total monthly losses for simplicity. Similarly, the river temperatures are shown as mean monthly values. These monthly temperatures were computed from the simulated daily river temperatures.

Annual salmon losses and benefits are summarized in Table 1 of the appendix. Tables 2-5 summarize monthly river temperatures and salmon losses for 1974-77, respectively. Tables 6-__are the mortality model output listings. The listings include monthly riverflows and temperatures at eight locations from Shasta Dam to Red Bluff, and computed salmon mortalities tabulated by month, race, and life stage.

Table 1 summarizes salmon losses (expressed as percent of salmon run) for the historical operation and the three structural alternatives. Salmon benefits (reductions in historical losses) for the three alternatives are also shown. The losses and benefits are tabulated for each study year (1974-77) and by race (fall, late-fall, winter, and spring). Total salmon losses and benefits for each year were computed by weighting the four races by average run size. The weighting factors were based on 10-year average (1971-81) numbers of salmon for each race: fall - 78,000, late-fall - 16,000, winter - 23,0900, and spring - 10,000. These numbers yield the following weighting

TABLE 9
Estimated Salmon Losses and Relative Reduction in Losses for Simulation Results of a Dry Year for Sacramento River Chinook Salmon

	Fall		Late-fall		Winter		Spring[a]		Total	
Alternative	Est.	Rel.[c]	Est.	Rel.	Est.	Rel.	Est.	Rel.	Est.[b]	Rel.
Historical	35.2	-	35.6	-	62.7	-	57.0	-	41.9	-
1	35.2	-	33.1	7.0	55.5	11.5	65.4	-	41.0	2.
2	32.1	8.8	28.6	19.7	38.6	38.4	70.2	-	35.8	14.
3	31.1	11.6	29.1	18.2	44.3	29.3	70.5	-	36.3	13.

[a] Calculations were not done for spring-run because of problems with the simulation.
[b] Total loss is a weighted value based on relative strength of the runs.
[c] Relative loss standardizes the percent loss of comparative purposes. It is calculated by subtracting the percent loss for the alternative (%A) from percent loss for historical conditions (%H) and dividing the latter into the result and multiplying by 100.

$$\frac{(\%H - \%A)}{\%A} \times 100$$

1. Alternative 1. This alternative consists of diversion tunnels located at elevations 650 and 815 feet MSL. It achieves a marginal reduction in salmon losses compared to estimated historical losses and decreases total losses by about 2 percent for a dry year. Winter-run salmon losses are decreased by about 11 percent under this alternative relative to historical conditions.

2. Alternative 2. This alternative consists of diversion tunnel at elevation 650 feet MSL along with a multilevel withdrawal structure with eight ports ranging in elevation from 742 feet MSL to 1050 feet MSL. It is seven times more effective in reducing salmon losses than Alternative 1. It decreases winter-run losses by an additional 27 percent, which is a

significant savings. This equates to an additional 12,744 winter-run fish returning annually, if their numbers can be restored to the average pre-drought run size of 47,500 fish.

2. Alternative 3. This alternative consists of a multilevel withdrawal structure with eight ports ranging in elevation from 742 feet MSL to 1050 feet MSL. This alternative is intermediate to the other alternatives in reducing salmon losses. Overall, it reduces salmon losses by a factor of six over decreased losses for Alternative 1. When one considers total losses, it is only slightly less favorable than Alternatie 2.

Because of its greater depth and storage capacity, Shasta Lake influences water temperatures much more than Keswick Lake. Keswick Dam reregulates releases from Shasta Dam. As a reregulating reservoir, the water turns over too quickly to influence river temperatures very much. Analysis of the temperature profile in Shasta Lake provides important information as to the range of temperatures that is available for downstream releases.

The projected temperature profile in Shasta Lake for Alternatives 2 and 3 is included in Table 10. Results for the diversion structure are not included because it does not reduce salmon losses as much as the other alternatives.

Shasta lake water temperatures are relatively constant over time and for the two alternatives during July and early August. For Alternative 3, temperatures increase rapidly from day 220 to 230 at Outlet 1, but it is still 12 F warmer than at the diversion structure intake. Although the water temperature at the diversion structure intake increases rapidly from day 230 to 240, it is still cooler than at Outlet 1. This situation prevails until

Table 10

Surface elevation and water temperatures for the selected outlet ports in Lake Shasta for the simulation of the multilevel outlet alternative and the combination of the multilevel outlet and diversion structure alternative for July through October.

Day		Surface	Outlet 4	Outlet 3	Outlet 2	Outlet 1	Diversion Structure
		Elevation (feet)					
			942	902	815	742	650
			Temperature (F)				
July							
190	3	960	69	64	48	46	45
	2	953	69	63	50	48	47
200	3	943	72	68	50	46	46
	2	947	72	68	53	50	49
210	3	930		73	59	47	46
	2	934		73	59	54	51
August							
220	3	924		72	65	50	47
	2	927		72	64	56	56
230	3	917		70	68	58	47
	2	920		70	67	63	60
240	3	911		70	69	63	48
	2	914		70	69	65	63
September							
250	3	904		71	70	66	48
	2	907		71	70	67	65
260	3	897			70	64	49
	2	901			70	66	65
270	3	904		69	69	62	50
	2	907		69	69	65	63
October							
280	3	904		68	68	60	51
	2	907		68	68	63	61
290	3	911		67	67	57	52
	2	914		67	67	90	56
300	3	917		64	64	56	52
	2	920		65	65	56	54

3-Alternative 3(MLO) 2-Alternative 2(MLO and diversion structure) late September. At that point, the water temperature at the diversion intake for Alternative 1 exceeds that for Outlet 1 of the simulation for Alternative 3. The cool water at the lower level has been depleted by day 260 leaving only warm surface water.

The key point is that up to day 270, late September, the temperature difference between Outlet 1 and the diversion structure intake exceeds 10 F for Alternative 3. This clearly illustrates that much greater ability to control water temperature is gained by the additional 92 feet. This adds significantly more operational flexilibility into the system.

Alternative 2 provides water temperatures less than or equal to 58 F, down to Cottonwood Creek through August, as shown on Table 11. Egg and alevin mortality is minimal at these temperatures, less than 13 percent. Temperature induced mortality will be higher for the other alternatives than for Alternative 1, which is 100 percent. For Alternative 3, egg and alevin mortality in August is projected to be 50 and 80 percent at Cottonwood Creek and Red Bluff, respectively. Obviously, water temperatures cannot be controlled during September in a dry year. No form of temperature control is effective during September because Shasta Lake water levels are so low and the entire water column is readily warmed.

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TABLE 11
Simulated Mean Monthly Water Temperatures for a Dry Year at Selected Locations in the Sacramento River for the Three Alternatives

	Water Temperature (°F)		
Month	Keswick Dam	Cottonwood Creek	Red Bluff
July			
Historical	56.6	59.2	60.5
Alternative 1	52.6	56.1	57.8
Alternative 2	51.8	55.4	57.2
Alternative 3	51.9	55.5	57.3
August			
Historical	62.5	63.3	63.6
Alternative 1	60.8	61.9	62.4
Alternative 2	56.4	58.5	59.5
Alternative 3	58.3	60.0	60.8
September			
Historical	61.9	62.9	63.0
Alternative 1	61.7	62.7	63.0
Alternative 2	61.5	62.5	62.8
Alternative 3	61.1	62.3	62.6
October			
Historical	56.0	56.6	56.6
Alternative 1	55.8	56.5	56.4
Alternative 2	55.8	56.5	56.4
Alternative 3	55.7	56.5	56.4

The combination of the multilevel outlet and diversion structure (Alternative 2) benefits salmon the most for dry year conditions. A 6.1 percent total benefit is achieved with this alternative, while Alternative 3 alone provides a 5.6 percent total benefit to salmon, as shown in table 12.

TABLE 12
Salmon Benefit Summary of the Three Alternatives

Year	Alternatives	Salmon Benefits						
1974 (Wet)	1	.7	(.9)	.5	.7	2.3	.8	(.9)
	2	1.6	(2.2)	.3	1.7	6.1	1.8	(2.2)
	3	1.6	(2.2)	.3	1.8	6.0	1.8	(2.2)
1975 (Normal)	1	.4	(.5)	.2	.3	1.4	.4	(.4)
	2	4.5	(5.0)	.5	1.2	3.7	3.3	(3.6)
	3	4.5	(5.0)	.5	1.1	3.5	3.3	(3.6)
1976 (Dry)	1	0	(.7)	2.5	7.2	-8.4	.9	(1.3)
	2	3.1	(5.5)	7.0	24.1	-13.2	6.1	(7.6)
	3	4.1	(7.0)	6.5	18.4	-13.5	5.6	(7.4)
1977 (Critical)	1	-1.3	(-2.1)	5.7	5.1	-1.2	.7	(.3)
	2	.8	(-1.9)	7.3	5.6	-1.5	1.2	(.7)
	3	.4	(.3)	6.8	3.0	-.3	1.5	(1.6)

1/ H - Historical, 815'
1 - Diversion Tunnel - 650', 815'
2 - Diversion Tunnel + MLO - 650', 742' - 1,050'
3 - MLO - 742' - 1050'

2/ % years drier
3/ Historical less - A.T. less
4/ Weighter - (F - 61.4%, L.F. - 12.6%, H - 18.1%, S - 7.9%)

Benefits resulting from these two alternatives appear to be relatively close. The actual differences are masked because of the way total benefits are calculated. Upon closer examination, Alternative 2 is significantly better because of its effect on improving conditons for winter-run fish. The benefits for these fish are 33 percent grater than those for Alternative 3 and 350 percent greater than those for Alternative 1. Alternative 1 does not influence water temperatures as much and resulting benefits are significantly

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(dry) and 1931 (critical), and no significant impacts occured in 1954 (normal) and 1958 (wet). Shasta storage level is the most important factor affecting downstream temperatures. Based on the operation studies, the frequency of occurrence of years with Shasta storages similar to 1934 was ____ in 76 years at the 1980 level and _____ in 76 years at the 2020 level. The negative impacts to salmon at the 1980 level were substantially greater than the positive impacts at the 2020 level. Generally, the flow alternatives with the highest impacts were those with 4500 cfs in critical years (i.e., Alternatives 1 and 2.

RESULTS OF OPERATIONS STUDIES

Structural

Because the structural alternatives assumed no change in existing facilities, or flows, there were no impacts to the CVP yield.

Nonstructural

Table 13 summarizes the impacts on the CVP's water supply yield and the key parameters affecting this yield for the nonstructural alternatives.

In all cases, the results of the operations studies, performed at the year 2020 level of development, show a reduction in yield for the alternatives providing for increased Upper Sacramento River flows as compared to the base study incorporating the existing Upper Sacramento River flow requirements. The primary reason for the CVP yield reductions is the timing of the increased Sacramento River fish flows. The flow increases are required year round. Increased releases in summer months, for the most part, do not exceed the multiple purposes of irrigation, navigation, and Delta requirements, and thus

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TABLE 13
Impacts of Nonstructural Alternatives on CVP Yield

Alt	Upper Sacramento Flow Criteria Wet/Normal Year	Dry Year	Critical Year	Decrease In Yield	Increase In Total Critical Period Surplus	Increase In Usable Surplus
	(cfs)			(thousand acre-feet)		
1	6000	6000	4500	689	4511	207
2	6000	4500	4500	620	4014	183
2	6000	4500(BN)*	Existing	375	2465	118
4	6000(BN)*	Existing	Existing	283	1896	118

* Indicates that flow requirement is also in effect for below normal year.

are not lost. In the winter months, however, these multipurpose requirements are lower, increased single purpose fish releases are required. Surplus flows in the Delta tend to occur in these months even under the existing Sacramento River flow criteria. Therefore, the increased single purpose fish releases increase these Delta surpluses. When an increase in Delta surpluses occurs as during the 1928 through 1934 critical period, the result is a loss of CVP firm yield. As shown on Table 13, a very low percent of these Delta surpluses is usable for water supply purposes. For this reason, the reductions in CVP yield are significant, especially for those alternatives with high Sacramento River flow requirements in dry and critical years.

RESULTS OF RESERVOIR ANALYSIS

Results of the above comparisons indicate little difference in standing crop values when comparing alternatives within a single water year or for all water years combined. This held true for both the 1980 and 2020 levels of development for Clair Engle, Folsom, and Shasta Reservoirs.

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the 815-foot penstock level if they are to pass through the powerplant.

TABLE 14
Annual Power Losses

Year	Percentage Years Drier	Alternative Plan 1 million kilowatthours (kWh)		
		Alterantive 1	Alternative 2	Alternative 3
1974	99	50.5	43.5	43.1
1975	63	43.8	49.7	44.1
1976	12	25.2	38.2	26.3
1977	1	16.7	21.0	12.5
Average Annual Power Loss		37.6	36.4	43.2

The value of the lost power was calculated using Federal Energy Regulatory Commission fuel escalation methodology. No studies were done to determine the reduction in project dependable capacity for the various alternatives, but it is estimated that such a reduction and the associated loss of revenue would be significant. Reductions in generation would also reduce the power accomplishments of the CVP.

The years 1974-77 were selected as a representative sampling of historical Shasta releases. This period includes the most severe drought in the history of Shasta Dam (1976-77). The years 1974-75 are representative of normal water years. Monthly historical releases were obtained from existing operational needs.

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To determine power losses, the monthly historical releases were matched with existing power generation records. From those figures, the average monthly hydraulic head was calculated using the formula:

$$\text{Head (feet)} = \frac{\text{Generation (kWh)}}{\text{Flow (TAF)} \; * \; \text{Plant Efficiency (\%)} \; * \; 1.025}$$

Using this power head calculation, power generation was derived by rearranging the equation. Included were the additional head losses due to the modified intake structure.

$$\text{Generation (kWh)} = \text{Head (feet)} * \text{Flow (TAF)} * \text{Plant Effcy (\%)} * 1.025$$

This generation was then compared with historical generation records. Resulting losses are shown on Table 15.

studies was extremely rigid, resulting in very little flexibility for power releases in the American River system. These two factors combined to make the project dependable capacity determination for the 1980 level studies questionable. For now, the current methodology was used, but the method of project dependable capacity determination is being renegotiated between PG&E and the United States government.

TABLE 17
Impacts of Nonstructural Alternatives on CVP Power Accomplishments

Alt.	Project Dependable Capacity 1980 Level (MW)	Project Dependable Capacity 2020 Level (MW)	Average Annual Generation 1980 Level (GWh)	Average Annual Generation 2020 Level (GWh)	Net Change In Annual Power Benefits From Base Study ($1,000,000)
Base a/	934	795	3506.7	3191.5	N/A
1 b/	477	872	3501.2	3351.6	-12.57
2 c/	936	872	3423.7	3374.5	2.32
3 d/	936	891	3442.0	3347.4	3.89
4 e/	936	891	3451.8	3350.3	3.48

a/ Existing agreement flows in all year types.
b/ 6000 cfs (wet, normal, & dry); 4500 cfs (critical).
c/ 6000 cfs (wet, normal); 4500 cfs (dry and critical).
d/ 6000 cfs (wet, normal); 4500 cfs (dry); existing agreement (critical)
e/ 6000 cfs (wet, normal); existing agreement (dry ,critical).

Assumptions: $79.00/MWh used as annual equivalent energy value; $60.70/kW-year used as capacity value; project on line date of 1990; annualized at 8-5/8 percent interest over 100 years.

Atternative 1 requires special mention. This is the alternative that proposes flow below Keswick Dam of 6,000 cfs for wet, normal, and dry years and 4,500 cfs in critical years. Long-term operation studies indicate Shasta

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storage going down to 220,0000 acre-feet, well below Shasta's minimum power pool of 562,000 acre-feet. If Shasta were to be operated this low, no power would be produced during the periods when storage was below 561,000 acre-feet. Project dependable capacity was therefore determined without Shasta, resulting in this alternative showing a decrease of dependable capacity of 457 MWh.

All four alternatives show a decrease in average annual generation. Alternative 1 showed the least decrease because of the extremely low project dependable capacity which was used. This meant that existing mandatory releases were sufficient to meet the project dependable capacity and power-only releases were not necessary. (Shasta was incldued for long-term generation.) This allowed reservoirs to be maintained at higher overall storages and thus mandatory releases had higher heads and efficiencies.

The 2020-level studies for the four alternatives showed increased in project dependable capacity and average annual generation. For the 2020 level studies, water deliveries used in the alternatives were reduced from the base case deliveries. These reduced deliveries have a two-fold effect: first they result in less project power being required for pumping, and secondly, they allow extra water to be in the system which provides for a more flexible operation.

The short-term studies indicate that there would be a gain in project dependable capacity from 77 to 96 MWh, depending on the alternatives. Because of the decreased water deliveries, the 2020-level studies are more representative of the assumptions used in the determinations of project dependable capacity and are less likely to change as significantly if the method of determination is changed.

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occurrence diagram for the reduction in salmon mortality for each plan. This procedure was followed in developing average annual values for the three plans.

Percentage Reduction in Mortality. For these calculations 1974 and 1977 are set at 100 and 0 percent, respectively. Given the study schedule and budgetary constraints, it has been assumed that linear interpolation would be suitable to describe the relationship between hydrologic years and mortality reduction. In addition, this assumption greatly simplifies the computation of the average annual mortality reduction. The following expression shows the computation for the case illustrated above.

$$\text{Average Annual Mortality Reduction} = 0.37\left(\frac{0.8 + 0.4}{2}\right)$$

$$+ 0.51\left(\frac{0.4 + 0.9}{2}\right) + 0.12\left(\frac{0.9 + 0.7}{2}\right) = 0.6495$$

The current average annual post-Red Bluff Diversion Dam chinook salmon spawning run is estimated at 127,0900 fish. Under these conditions with no change to existing power facilities implementation of the diversion tunnel alternative would be predicted to reduce chinook salmon mortality by 825 fish per year.

The same method was followed in estimating reductions in salmon mortality for the other two alternative plans. Estimates of average annual chinook salmon mortality for the three plans evaluated include the estimated percentage of mortality reduction and its conversion to numbers of fish based on an average annual post-Red Bluff Diversion Dam run of 127,000. The power

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analysis for the alternatives includes only the effects on power production at the Shasta Powerplant. No attempt was made to assess the loss in project dependable capacity for the entire CVP power system. The power loss at Shasta is comprised of the losses in energy output, valued at $0.985 per kWh, and capacity, valued at $0.165 per kWh, for a total of $1.15 per kWh.

The power loss for each alternative was estimated for each of the four hydrologic years used in assessing the accomplishments of the three plans. The method used to convert accomplishments by hydrologic year to an average annual was also used in converting power losses for individual years to an average annual value. Power losses by alternative for individual years and the average annual are displayed in Table 19.

TABLE 19
Annual Power Losses

Year	Percentage Years Drier	Alternative 1	Alternative 2	Alternative 3
1974	99	50.5	43.5	43.1
1975	63	43.8	49.7	44.1
1976	12	25.2	38.2	26.3
1977	1	16.7	21.0	12.4
Average Annual Power Loss		37.6	43.2	36.4

Cost Effectiveness

The benefits and costs of the structural alternatives are compared on Table 20. The economic analysis of the structural alternatives focuses on cost effectiveness since appropriate size specific recreational salmon fishing

1934 were very dry years (Table 21). The percentage salmon mortality reduction for each of the five plans in the five selected years is shown in Table 22. The assumptions used in both computations were:

Base Case -	Existing flows	
Alternative 1 -	6000 (wet, normal, dry)	4500 (critical)
Alternative 2 -	6000 (wet, normal)	4500 (dry, critical)
Alternative 3 -	6000 (wet, normal)	4500 (dry),existing (critical)
Alternative 4 -	6000 (wet, normal)	Existing (dry, critical)

TABLE 21
Percentage of Years Equal to or Drier

1990 Year Type	Base	Alt 1	Alt 2	Alt 3	Alt 4	2020 Base	Alt 1	Alt 2	Alt 3	Alt 4
Wet (1958)	100	100	100	100	100	100	100	100	100	100
Normal (1954)	54	73	73	73	73	73	69	69	71	71
Dry (1923)	19	25	27	25	23	25	33	29	33	44
Critical (1931)	0	4	0	0	0	0	8	10	0	0
(1934)	15	4	2	10	17	10	4	2	4	4

TABLE 22
Percentage Reduction in Salmon Mortality

1980 Year Type	Base	Alt 1	Alt 2	Alt 3	Alt 4	2020 Base	Alt 1	Alt 2	Alt 3	Alt 4
Wet (1958)	N/A	1.5%	1.5%	1.5%	1.5%	N/A	.9%	.9%	9.0%	.9%
Normal (1954)	N/A	-.3%	.0%	.0%	.0%	N/A	.0%	.0%	.0%	.0%
Dry (1923)	N/A	-13.9%	-11.4%	-9.3%	-7.1%	N/A	-1.8%	2.1%	2.1%	5.0%
Critical (1931)	N/A	-9.1%	-9.6%	-9.0%	-9.2%	N/A	1.1%	5.5%	-1.9%	-2.4%
(1934)	N/A	-23.6%	-25.2%	-13.2%	-9.4%	N/A	3.6%	11.3%	1.0%	1.2%

Note: 1980 scenario assumed to equal 1990 (year 1 of project)
"--" figures represent increases to mortality

The information in Tables 21 and 22 was used to compute weighted (frequency of occurrence) reductions in salmon mortality for each plan at two levels of development (1980 and 2020), as shown on Table 23. The results vary greatly among alternatives and between levels of development. Because each alternative results in significant increases in mortality at the earlier 1990 level of development, this analysis studies the most optimistic scenario. It does so to find if the early losses are offset by later mortality reductions when viewed over a 100 years and annualized at 8-5/8 percent.

CHAPTER VI

FINDINGS AND CONCLUSIONS

There are many unanswered questions regarding the chinook salmon's life history and flow and temperature needs in the Upper Sacramento River. The flow and temperature studies described in this report were cursory and conducted within the constraints of existing data and methodologies. Further studies are necessary to refine our knowledge of Sacramento River chinook salmon and develop effective management procedures.

STRUCTURAL

The following conclusions can be drawn from the structural analysis:

1. Alternative 2 has the greatest rancge of elevations from which to drawwater. This combination adds significantly more flexibility to operations than either of the structures alone. In addition, alternative 2 is significantly better due to its effect on improving conditions for winter run fish. The benefits fro these fish are 33 percent greater than those for alternative 3 and 350 percent greater than those fro alternative 1.

2. Alternative 3 would be the best structural plan for temperature control. In terms of the temperature model the highest benefits occurred in 1976 with the winter race benefitting the most. Years with Shasta inflows similar to 1976 occurred in 7 out of 61 years based on 1922-82 runoff records. Most other years have had higher inflows, which reduced the benefits of temperature control. The mortality model results showed significant temperature-related salmon losses in all years studied. Ttoal losses were

Findings and Conclusions

4. Flow related wate temperature impacts on salmon were most severe for flow alternative 1 - minimum flow of 6,000 cfs for wet, normal and dry years and 7,500 cfs for critical years - and least severe for alternative 4 - minimum flow of 6,000 cfs for wet and normal years and existing agreement flows for dry and critical years.

5. Flow alternative 1 had the greatest negative impact on hydroelective power generation with an annual loss in power benefits of 12.57 million dollars. Flow alternative 3 (minimum flow of 6,000 cfs in wet and normal years, 4,500 cfs in dry years and existing agreement flows in critical years) had the greatest positive impacts on power generation with an annual gain in power benefits of 3.89 million dollars.

6. Flow alternative 1 had the greatest negative impact on firm yield water delivery with a decrease of 689,000 acre-feet. Flow scenario 4 had the least negative impact on firm yield with a decrease of 283,000. The dollar value of the firm yield loss for each alternative was 48,732,000 and 20,037,000, respectively.

7. The total annual cost, in terms of power generation and firm yield impacts of implementing the alternative flow scenarios range from $61,351,000 for alternative 1 to $16,557,000 fro alternative 4.

8. There were no significant impacts on reservoir fishery standing crop or annual sport harvest in Clair Engle Lake, Shasta Lake or Folsom Lake from any of the nonstructural flow alternatives. Water level fluctuations greater than 20 feet per month during sunfish spawning, occurred at each reservoir but the impact of this fluctuation could not be assessed.

Conclusions

1. There is a high cost associated with providing additional CVP water for fish improvement. The benefits attributable to such releases should be accurately assessed by state and federal agencies involved with CVP reservoir releases for fisheries.

2. The evaluation of fisheries impacts associated with the nonstructural flow alternatives should be considered preliminary pending developed development of additional essential information on flow-fish habitat relationships and on completion of a water temperature optimization model. State and federal agencies involved wth fisheries management activities on the Sacramento River should coordinate an effort to develop the necessary additional information.

3. Information should be developed to determine the relationship between river flow levels and salmon habitat in the Sacramento River. An instream flow study should be conducted to develop this information. The Instream Flow Incremental Methodology study on the Sacramento River, under the lead of the California Department of Fish and Game, should be strongly supported by federal and state agencies involved with fishery problems on the Sacramento River.

4. A water temperature optimization model for the Upper Sacramento River should be developed. Such a model would be of particular value to BOR since CVP reservoir operations could be optimized.

5. The effect of reservoir water surface fluctuations on reservoir fisheries in the three CVP reservoirs evaluated in this report should be

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APPENDED MATERIAL

APPENDIX A

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APPENDIX A

CVFWMS
Temperature Mortality Model
Fishery Assumptions

1. Fish upon reaching 70 mm migrate downstream from RBDD.

2. Fry and juveniles rear in the area where they hatch.

3. Food is not limiting.

4. Survival, growth are density independent.

5. Prespawning mortality: (use same temperature-mortality relationship as EGGS)

   Assume the following "arrival periods":

a.	Fall	Adults arrive at the spawning grounds prior to spawning	5 weeks
b.	Late-fall:	"	7 weeks
c.	Winter:	"	2 weeks
d.	Spring:	"	5 weeks

6. Spawning distribution by time (see table 1).

7. Life stages

   a. "PRESPAWNING ADULT" (see 5. above)

   b. "EGG": egg to fry (45 mm) (0 to 1300 TU).

   c. "FRY": fry to presmolt (45-70 mm) (1301-21--TU).

   d. "SMOLT": juveniles (>70 mm) (>2100 TU). If fall salmon do not reach "SMOLT" (>2100 TU) by June 1, they are assumed to die.

   $$TU = \sum_{i=1}^{n} (^\circ F-32)$$ - from egg deposition through day n

8. Temperature-mortality relationships: Table 2 (EGG); Table 3 (FRY)

9. Sacramento River salmon spawning distribution: Table 4 (Dry & Critical years); Table 5 (Normal year); Table 6 (Wet year); Table 7 (Pre-1970).

Table 3. 7-day mortality of chinook salmon fry and juveniles (45 mm - 70 mm) at various Sacramento River temperatures

Temperature °F	7-day mortality[a/] %	Daily mortality[b/] %
≤32	100	48.20
33	92.3	30.64
35	76.9	18.90
37	61.5	12.76
39	46.2	8.46
41	30.8	5.12
43	15.4	2.36
45 ≤ T ≤ 58	0	0
60	10.6	1.59
62	21.1	3.33
64	31.6	5.29
66	42.2	7.52
68	52.7	10.13
70	63.2	13.30
72	73.7	17.40
74	84.2	23.20
76	94.8	34.40
≥77	100	48.20

a/ Source: Gwill Ging, FWS - Sacramento.
b/ Computed by method shown on table 2.

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Table 4. Sacramento River salmon spawning distribution - %

Salmon spawning reaches

Dry and Critically Dry Years

SALMON RUN	1 KESWICK TO ACID	2 ACID TO HYWY 44	3 HYWY 44 TO AND, BR.	4 AND, BR. TO BALLS F.	5 BALLS F. TO JELLYS	6 JELLYS TO BEND	7 BEND TO RED BLUFF	8 RED BLUFF TO VINA BR.	9 VINA BR. TO ORD	10-YEAR AVERAGE SPAWING RUN
Fall	3.1	8.3	13.6	7.8	11.2	8.7	1.0	27.2	19.1	78,000
Late-fall	7.5	30.0	28.6	3.0	7.5	8.3	0.8	14.3	0.0	16,000
Winter (1981)	9.0	35.0	33.0	3.0	4.5	5.0	.5	10.0	0.0	23,000
Spring	0	27.8	7.3	14.5	8.5	1.3	.4	33.8	6.4	10,000
									TOTAL	127,000*

* Based on 1971-81 data
Tom Richardson, FWS

Table 7. Sacramento River salmon spawning distribution - %

Salmon spawning reaches

Pre-1970's

SALMON RUN	1 KESWICK TO ACID	2 ACID TO HYWY 44	3 HYWY 44 TO AND, BR.	4 AND, BR. TO BALLS F.	5 BALLS F. TO JELLYS	6 JELLYS TO BEND	7 BEND TO RED BLUFF	8 RED BLUFF TO VINA BR.	9 VINA BR. TO ORD
Fall	.8	23.4	33.3	16.9	10.5	4.1	2.9	7.0	1.1
Late-fall	7.5	30.0	28.6	3.0	7.5	8.3	0.8	14.3	0.0
Winter (1981)	9.0	35.0	33.0	3.0	4.5	5.0	.5	10.0	0.0
Spring	0	27.8	7.3	14.5	8.5	1.3	.4	33.8	6.4

(%) based on 1956-70 data

APPENDIX B

APPENDIX B

Sacramento River Temperature Simulations

The WQRRS reservoir model was used to simulate the heat budget of Shasta Reservoir for the years 1974 to 1977. Historic discharges and the simulated temperatures from Shasta were used as an upstream boundary condition for a stream temperature model of the Sacramento River from Shasta Dam to Red Bluff. A memorandum dated March 11, 1980, from Chief, Division of Research, to the Regional Director transmitted the results of the temperature simulations for historic releases, modified releases beginning in June for elevation 742 feet, and the measured USGS data at Bend Bridge.

Normally all releases are made through the hydraulic turbines to generate power. The only exception is for spillway releases. The modified releases were simulated to determine if cooler than historical downstream temperatures could be obtained by lowering the withdrawal elevation. Previous simulations showed that low level releases all year long did not achieve cooler downstream temperatures. Cooler temperatures could be obtained if historic release patterns were maintained until later that year, then shifted to low level releases to obtain cooler water.

Decreased temperatures were indicated below the dam for the 742-foot releases but no significant temperature change occurred below Clear Creek. During discussions between Bob George of the E&R Center and regional office personnel through the summer of 1980 and at a meeting in Sacramento in September 1980, it was decided to do the following additional studies.

1. Simulated historical releases until June, then use 650-foot releases for 1976 and 1977.

2. Simulate historical releases until October 15, then use 742-foot releases for 1975, 1976, and 1977.

3. Same as 2. but use 650-foot releases after October 15.

4. Simulate surface releases before October 15, then use 742-foot releases for 1975, 1976, and 1977.

5. Develop a new method of plotting the data so that the results of the different operations can be compared at each of the eight output points of the model.

The output points of the model are represented by the distance in miles below the dam enclosed in parenthesis: (1) below Shasta Dam (0.0), (2) above Spring Creek (8.0), (3) at Keswick (9.0), (4) above Clear Creek (23.3), (5) above Cow Creek (34.3), (6) above Battle and Cottonwood Creeks (43.7), (7) at Bend Bridge (52.8), and (8) at Red Bluff (65.1).

The new plotting program is capable of plotting data at all of the above points. However, only points 4, 7, and 8 were used to plot the data on figures 1 to 21. Each plot has a legend which identifies the data plotted with a particular symbol and a code. Codes used were: (a) YYHIS.REL implies historical releases for year YY, (b) YYJEEEHST implies historical releases before June 1, then releases from elevation EEE for year YY, (c) YYOEEEHST same as (b), except low level releases begin after October 15, and (d) YYEEESUR implies surface releases before October 15, then release from elevation EEE.

Figures 1 to 12 are plots of the data sent with the March 10, 1980 memorandum and the results of the 650-foot releases beginning in June for 1976 and 1977. The first six figures are self explanatory. Figure 6 to 12 are warmer than either historical releases or 742-foot releases during the last part of the year. This was because all the cold water was removed from the reservoir at elevation 650 by October. This cold water was replaced by warm water and late fall release temperatures increased about 1 °C. However, cooler water was released from the first of June until the end of September. Because all the cold water was removed by October by the 650-foot releases, warmer fall temperatures occurred. This condition is not good for fall fish spawning which needs cooler water.

Figures 13 to 21 are for releases with conditions that change October 15. Naturally, the curves follow the historical releases until October 15. A paradox occurs with the lowest, 650-foot outlet, having higher temperatures than the 742-foot releases. This is caused by all the cold water being removed because the volume below elevation 650 is much smaller than the volume released. This caused the temperature profiles to be shifted down in the water column and the discharge temperatures increased more than for the 742-foot releases. Surface releases before October 15 were warmer in 1975 than for other conditions. During 1976, the water surface fell below the 942-foot outlet and the surface release was shifted to elevation 842 feet at about day 185. This caused the abrupt temperature change of about 6 °C on figures 16, 17, and 18. After day 210, the temperature profile for both the surface releases and other modified conditions were very similar. Typically, a deep reservoir, like Shasta, has a epilimnion of about 10 meters depth then nearly constant temperature to the bottom of the reservoir. Any withdrawals from the constant temperature region are insensitive to the elevation of withdrawal. Two exceptions to this are: (1) When the thermocline is shifted down by deep withdrawals removing the coldest water from the bottom or by surface withdrawals removing most of the warm water at the surface and shifting thermocline upward and (2) when the total volume of the reservoir is greatly reduced as in 1977.

Fall temperatures in 1977, figures 19 and 21, for surface releases were cooler than other conditions because the thermocline was shifted upward. Any condition that shifts the thermocline upward or downward affects a large volume of water, but the change in temperature in only about 1 or 2 °C.

[redacted]

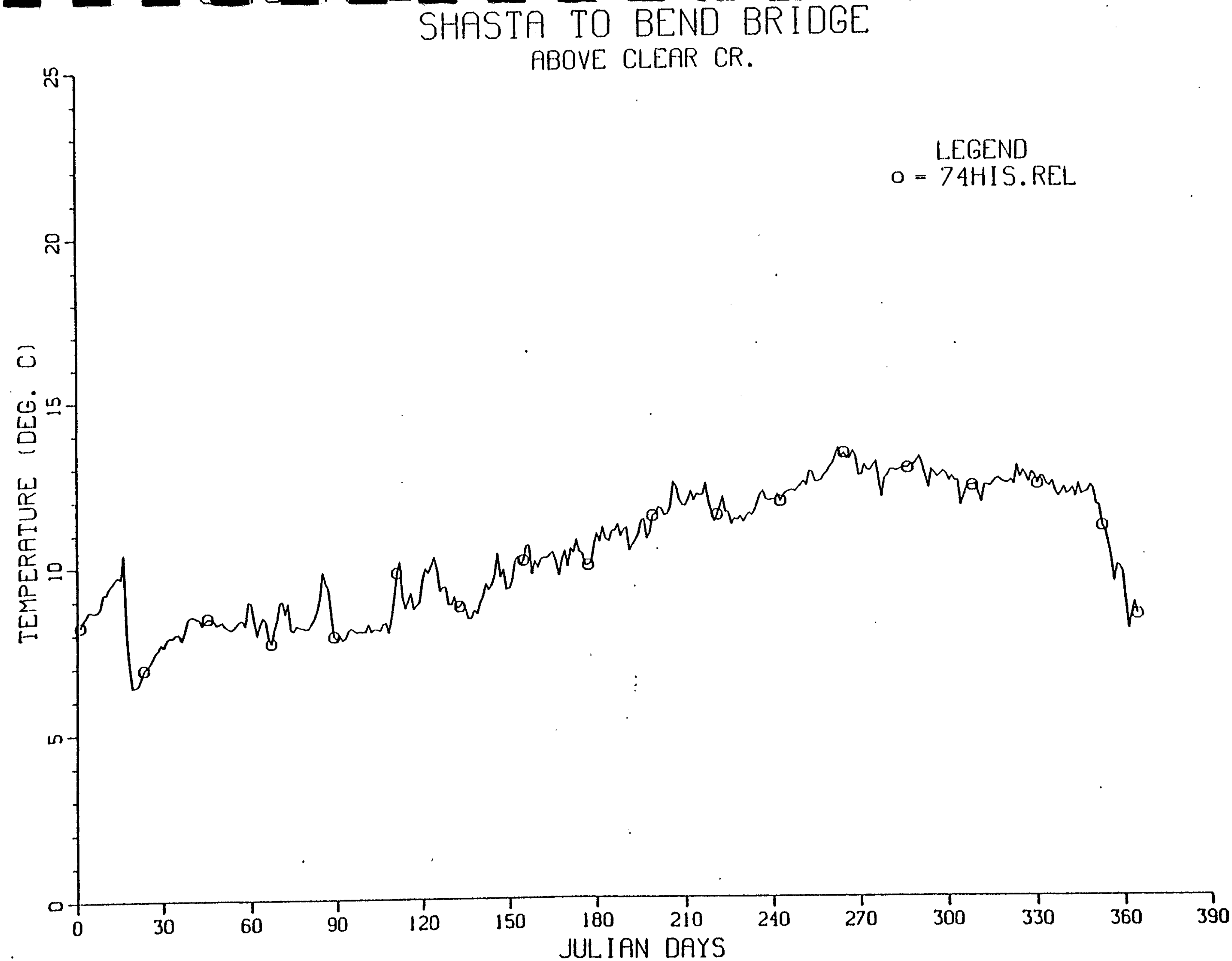

Figure 1. - 1974 Temperatures for Historic Data, Above Clear Creek

C-044566

C — 0 4 4 5 6 6

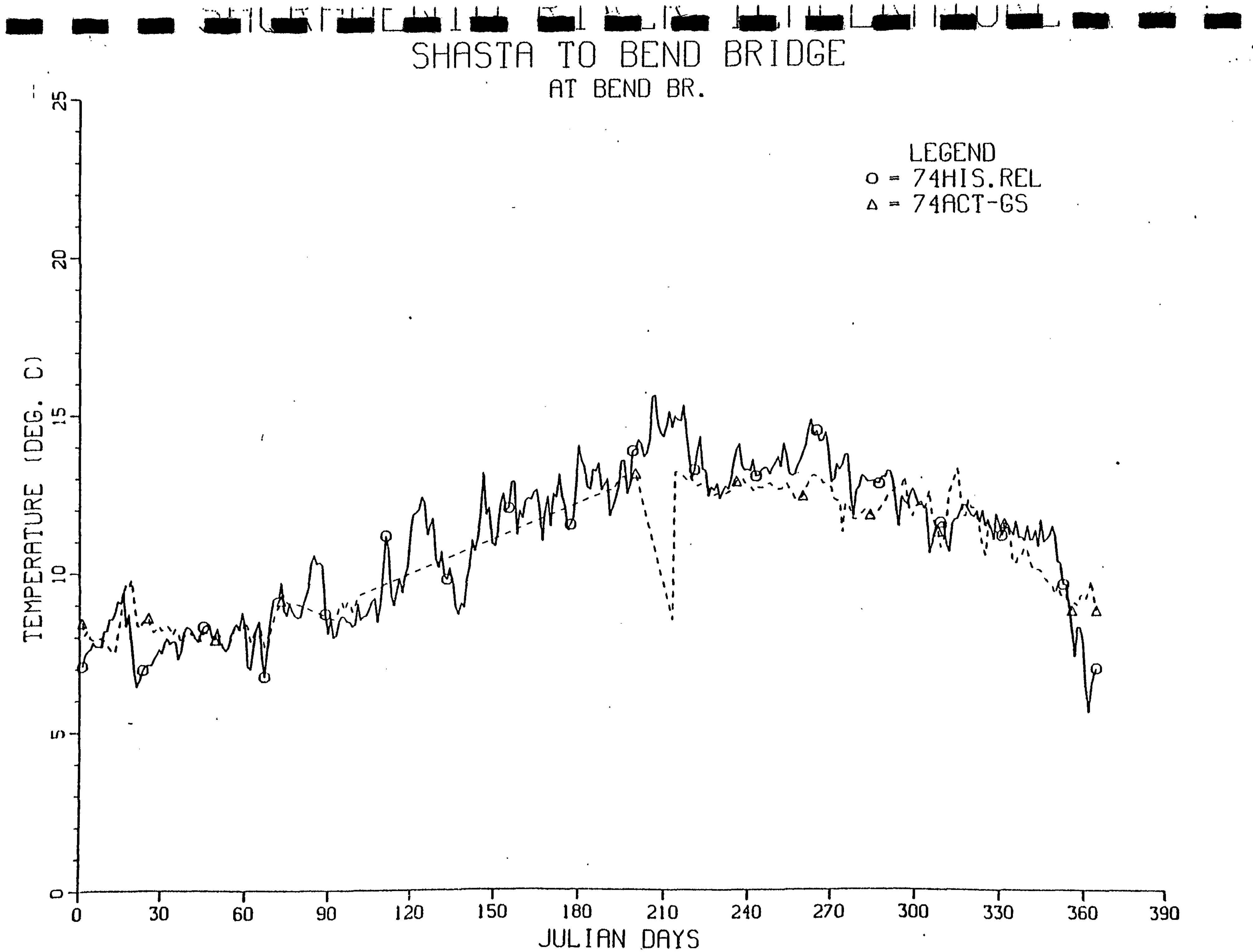

Figure 2. - 1974 Temperatures for Measured and Historic Data, at Bend Bridge

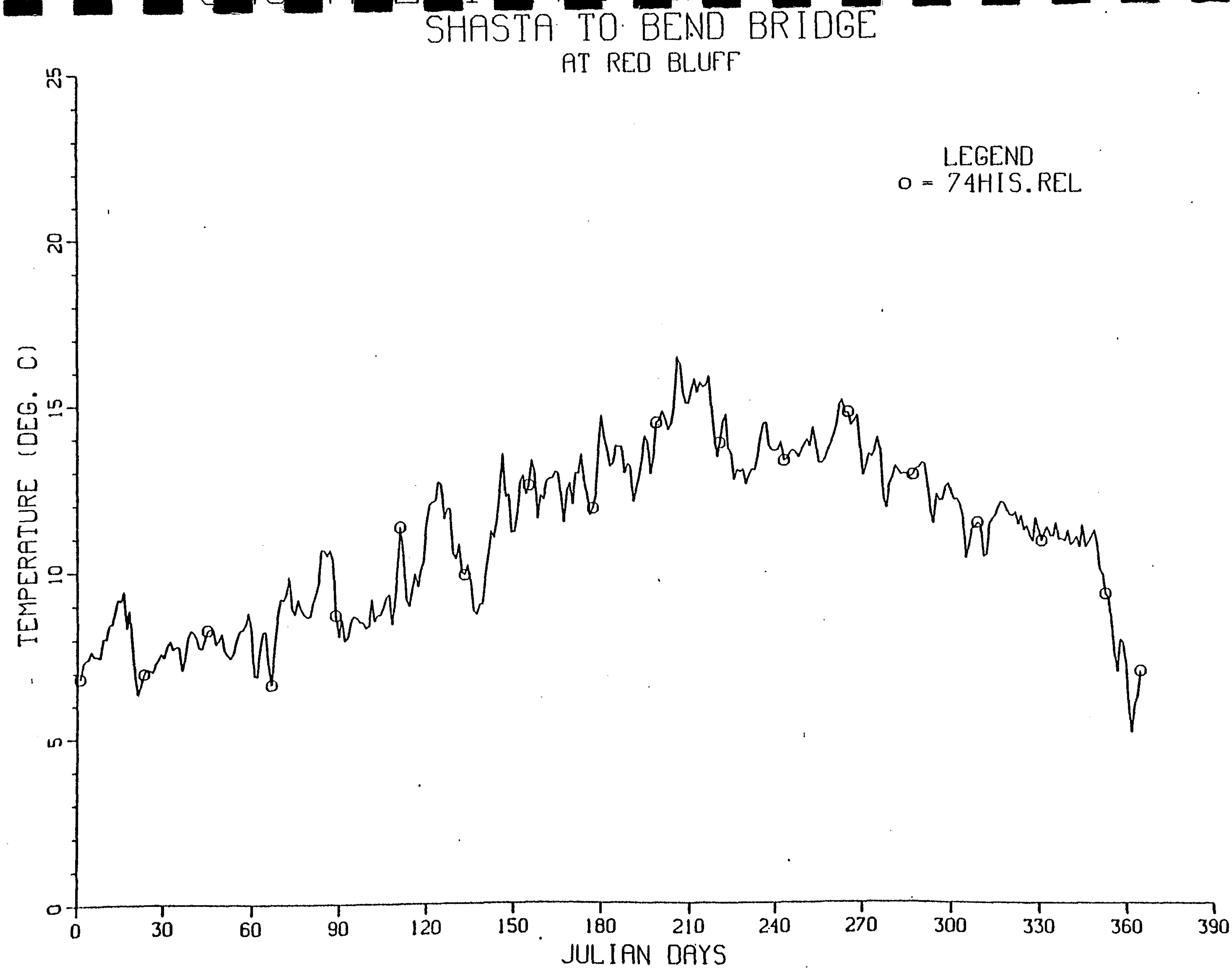

Figure 3. - 1974 Temperatures for Historic Data, at Red Bluff

[redacted]

SHASTA TO BEND BRIDGE

ABOVE CLEAR CR.

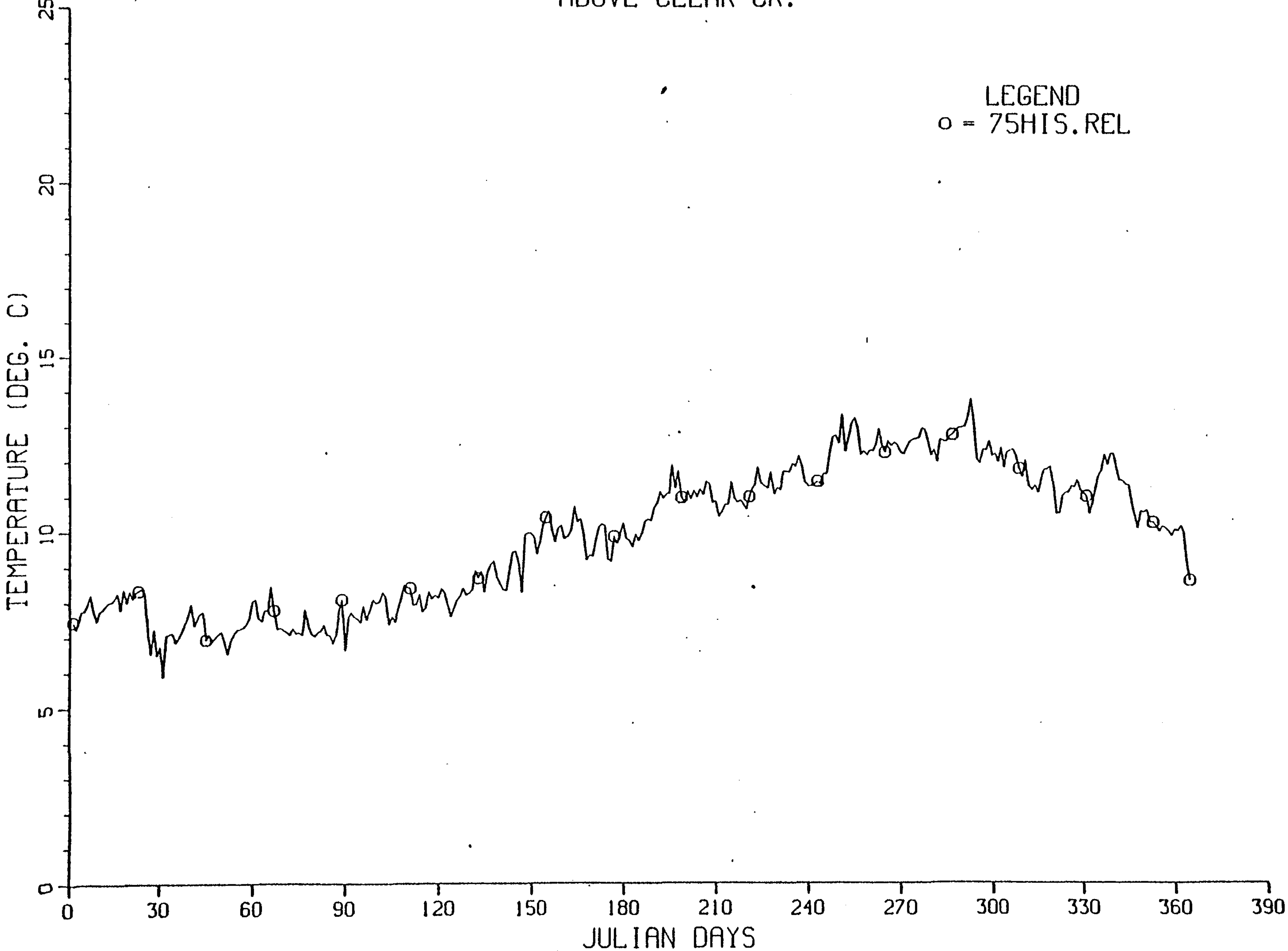

Figure 4. - 1975 Temperatures for Historic Data, above Clear Creek

C-044569

C — 0 4 4 5 6 9

[redacted]

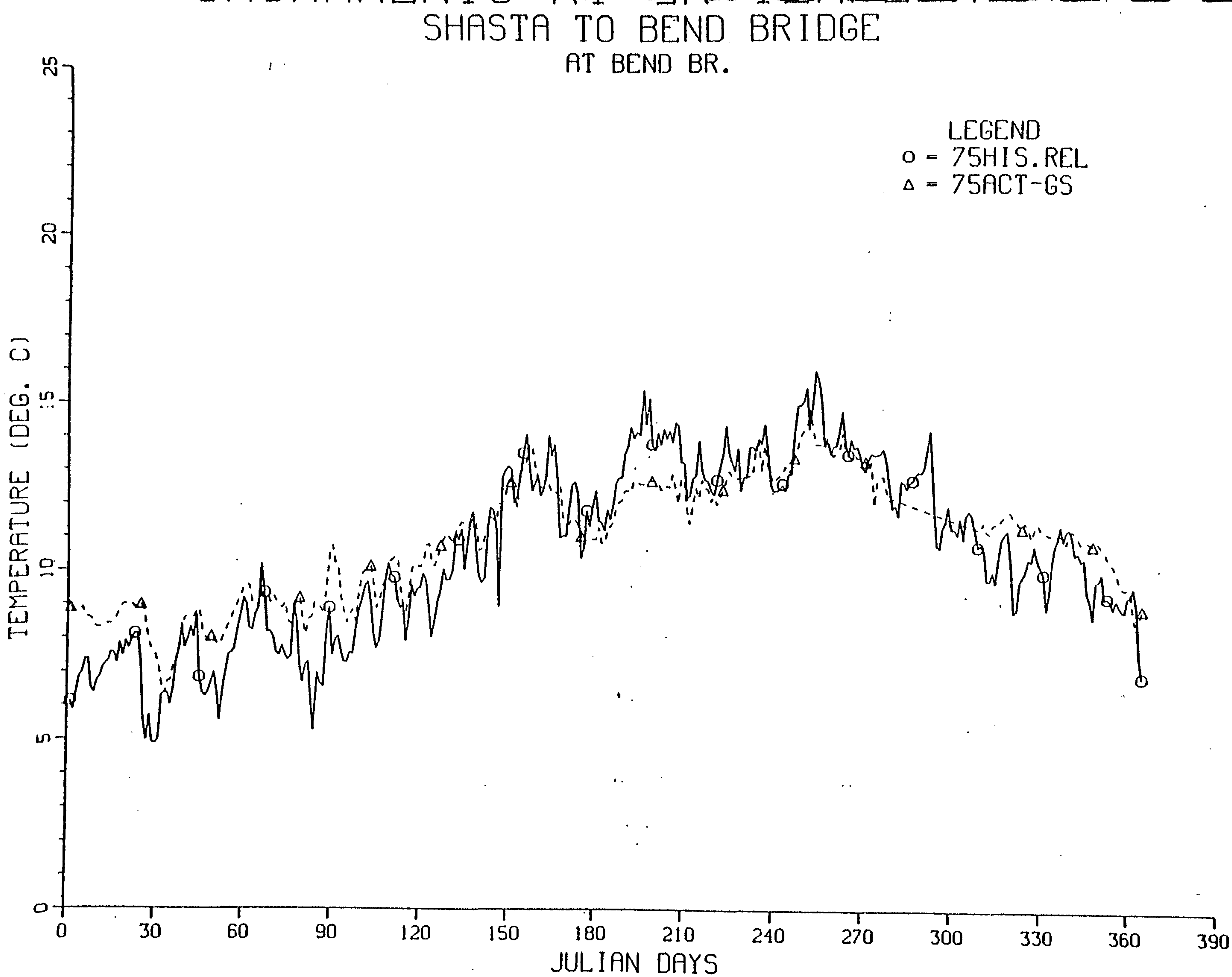

Figure 5. - 1975 Temperatures for Measured and Historic Data, at Bend Bridge

C-044570

C-044570

[redacted]

SHASTA TO BEND BRIDGE

AT RED BLUFF

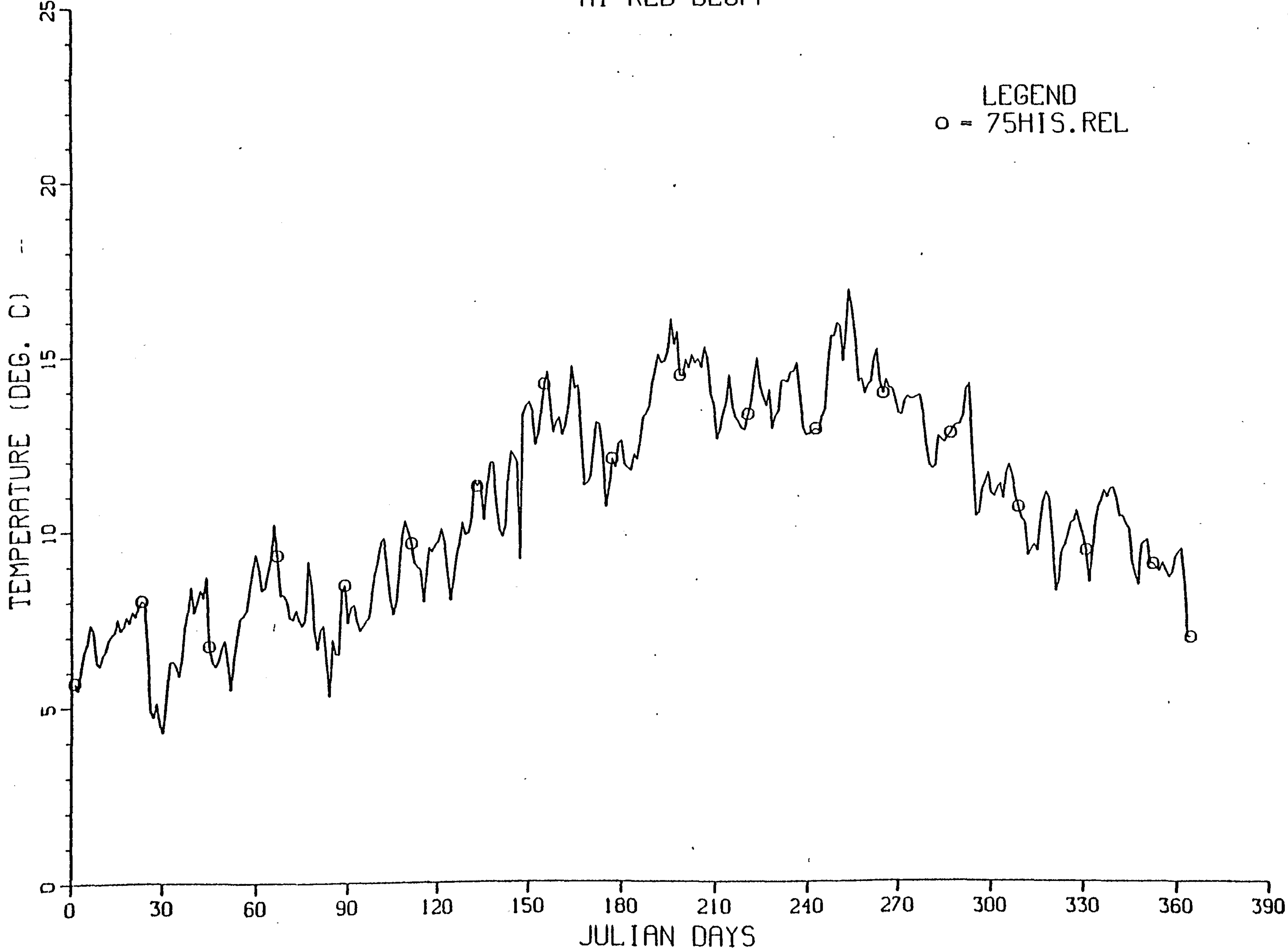

Figure 6. - 1975 Temperatures for Historic Data, at Red Bluff

C-044571

[redacted]

SHASTA TO BEND BRIDGE

ABOVE CLEAR CR.

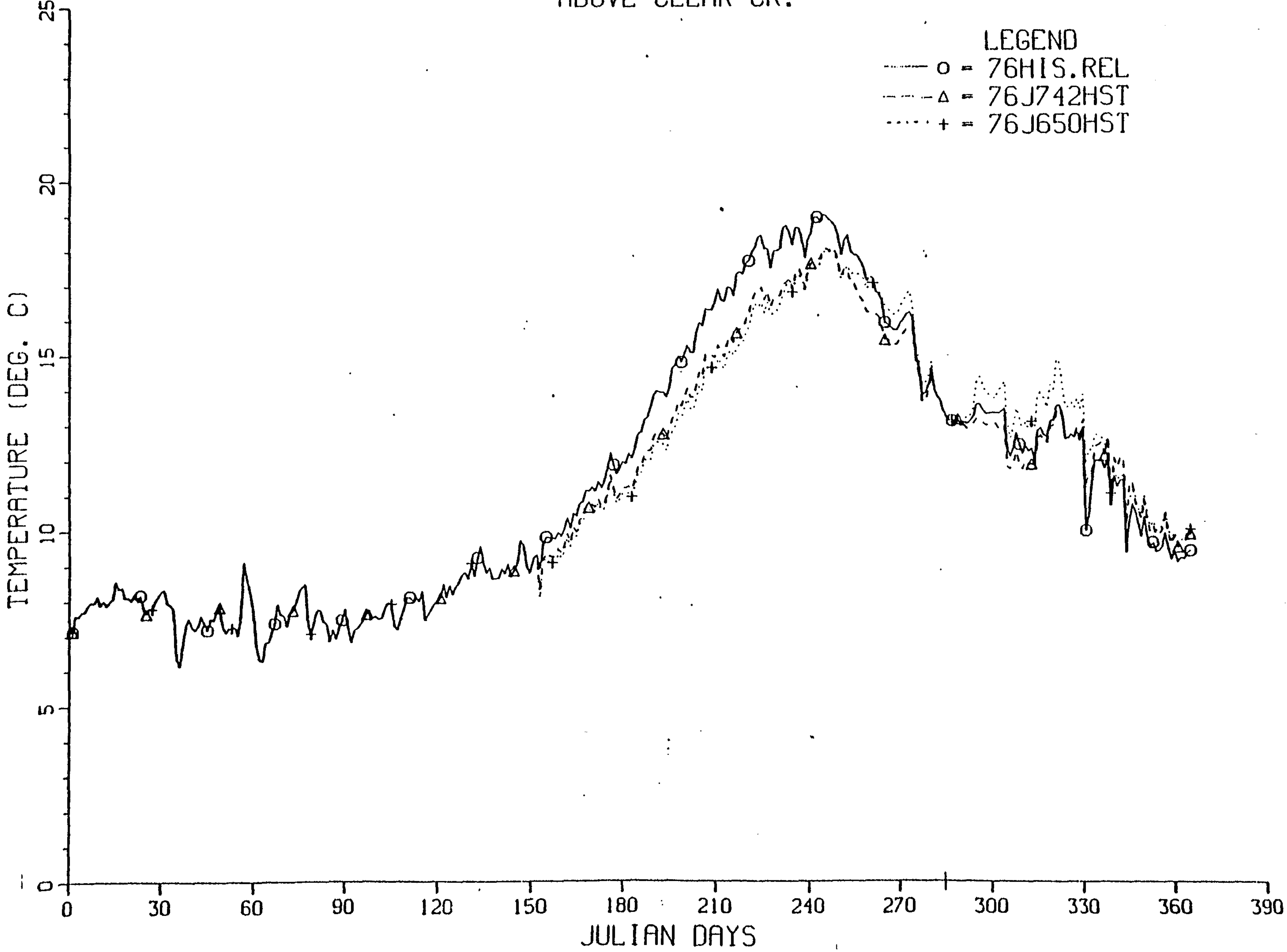

Figure 7. - 1976 Temperatures for Historic and Modified Releases for

C-044572

C — 0 4 4 5 7 2

[redacted]

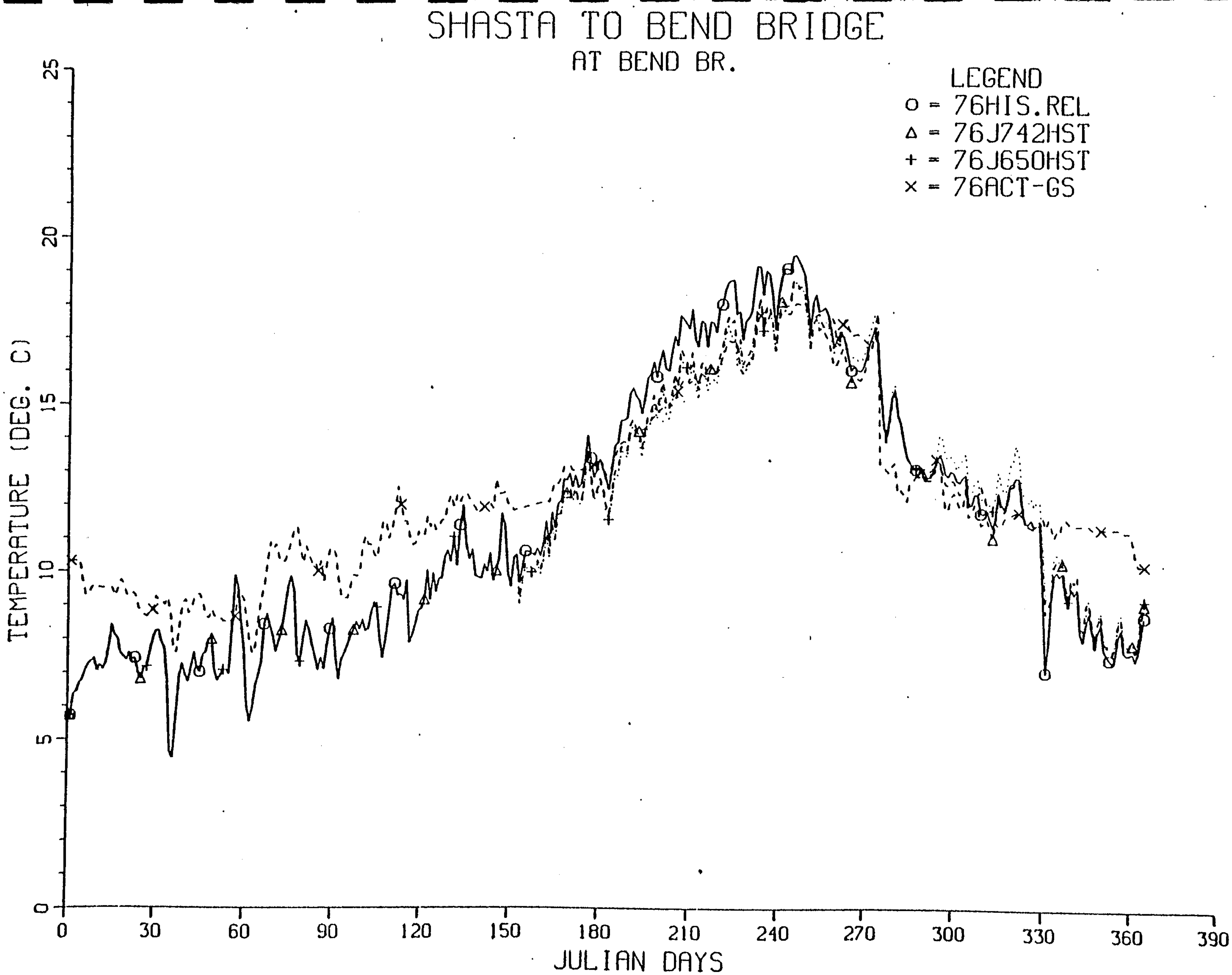

Figure 8. - 1976 Temperatures for Historic Data and Modified Releases for 650- and 742-foot elevations at Bend Bridge

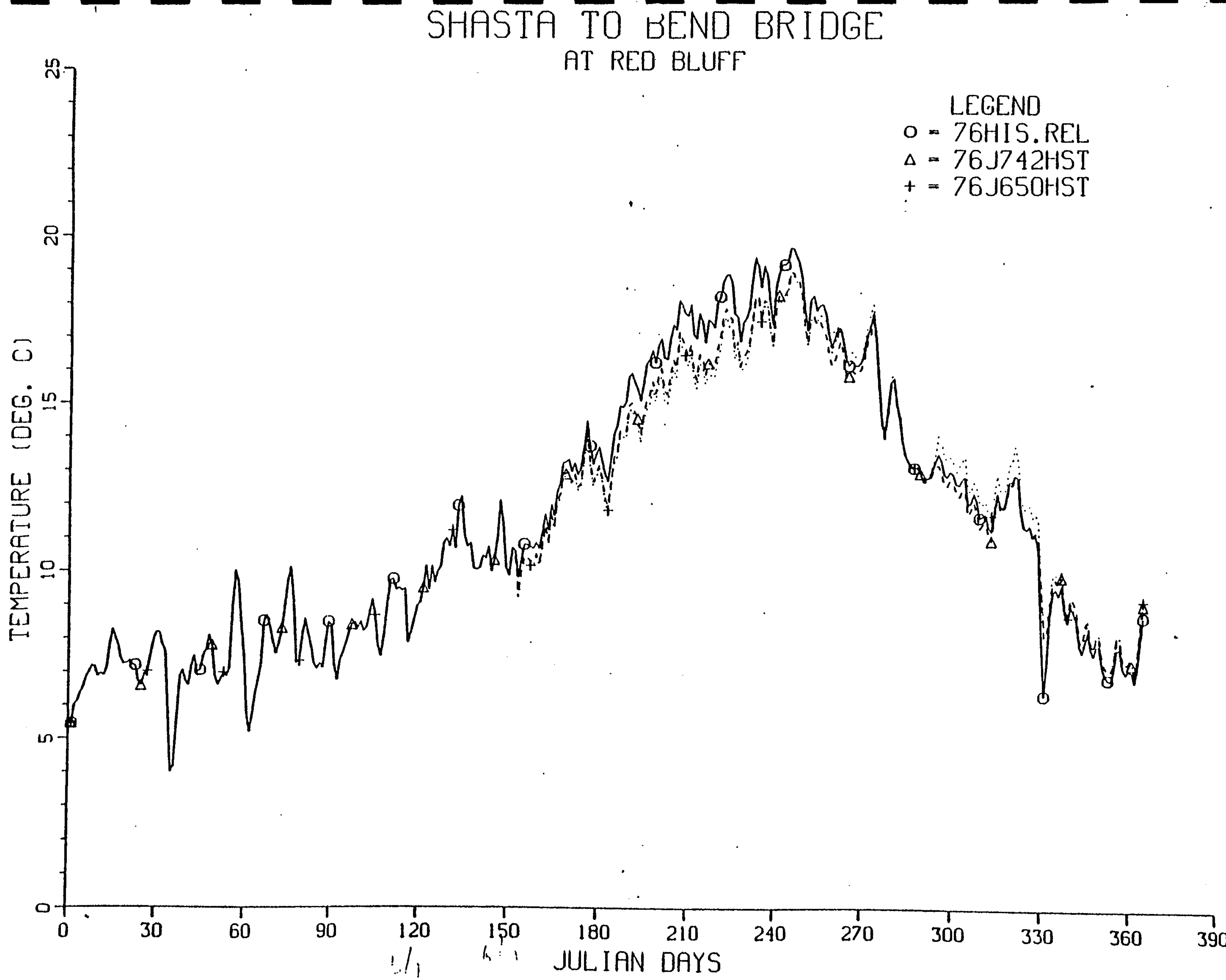

Figure 9. - 1976 Temperatures for Historic Data and Modified Releases for 650- and 742-foot elevations at Red Bluff

C-044574

C-044574

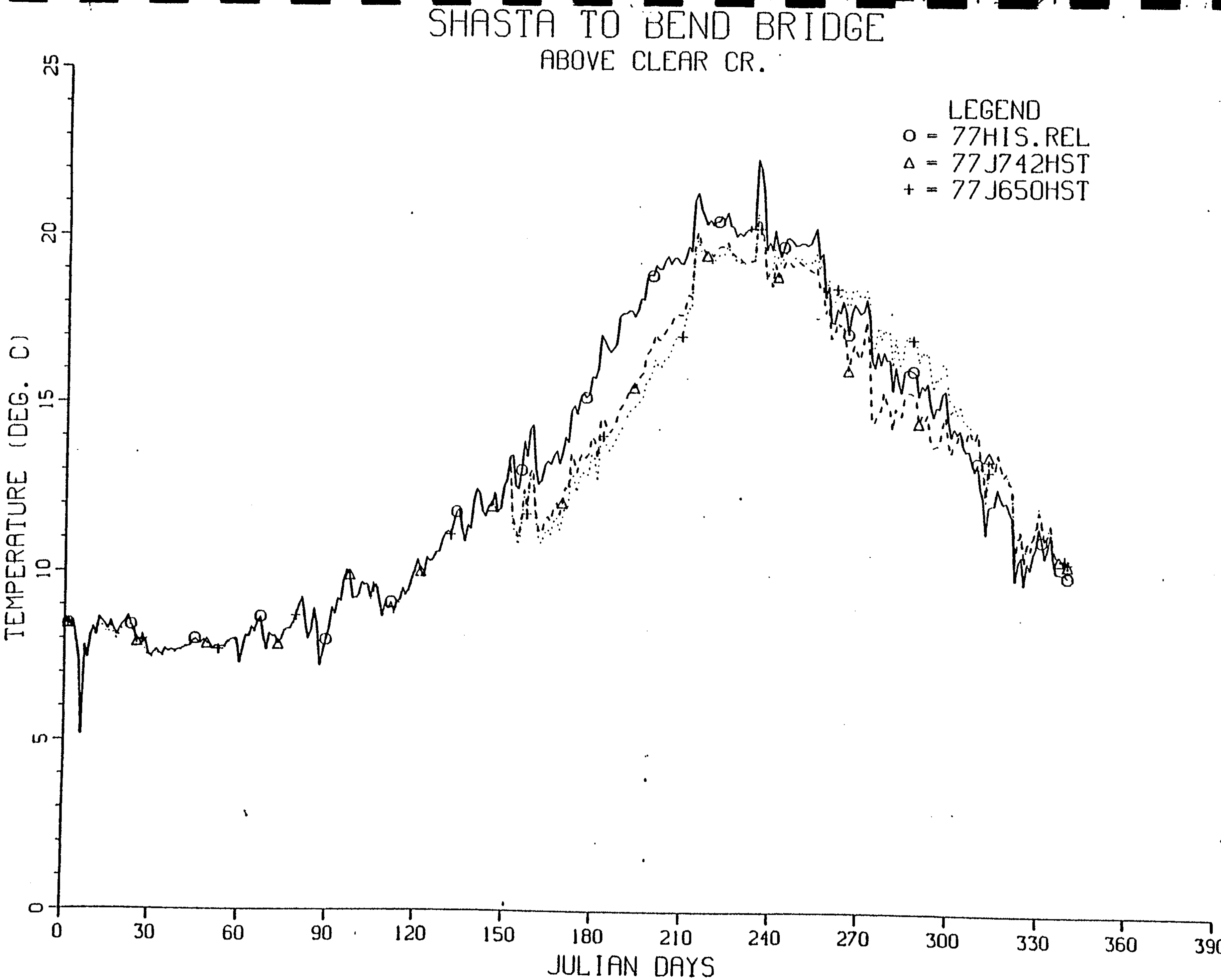

Figure 10. - 1977 Temperatures for Historic Data and Modified Releases for 650- and 742-foot elevations, above Clear Creek

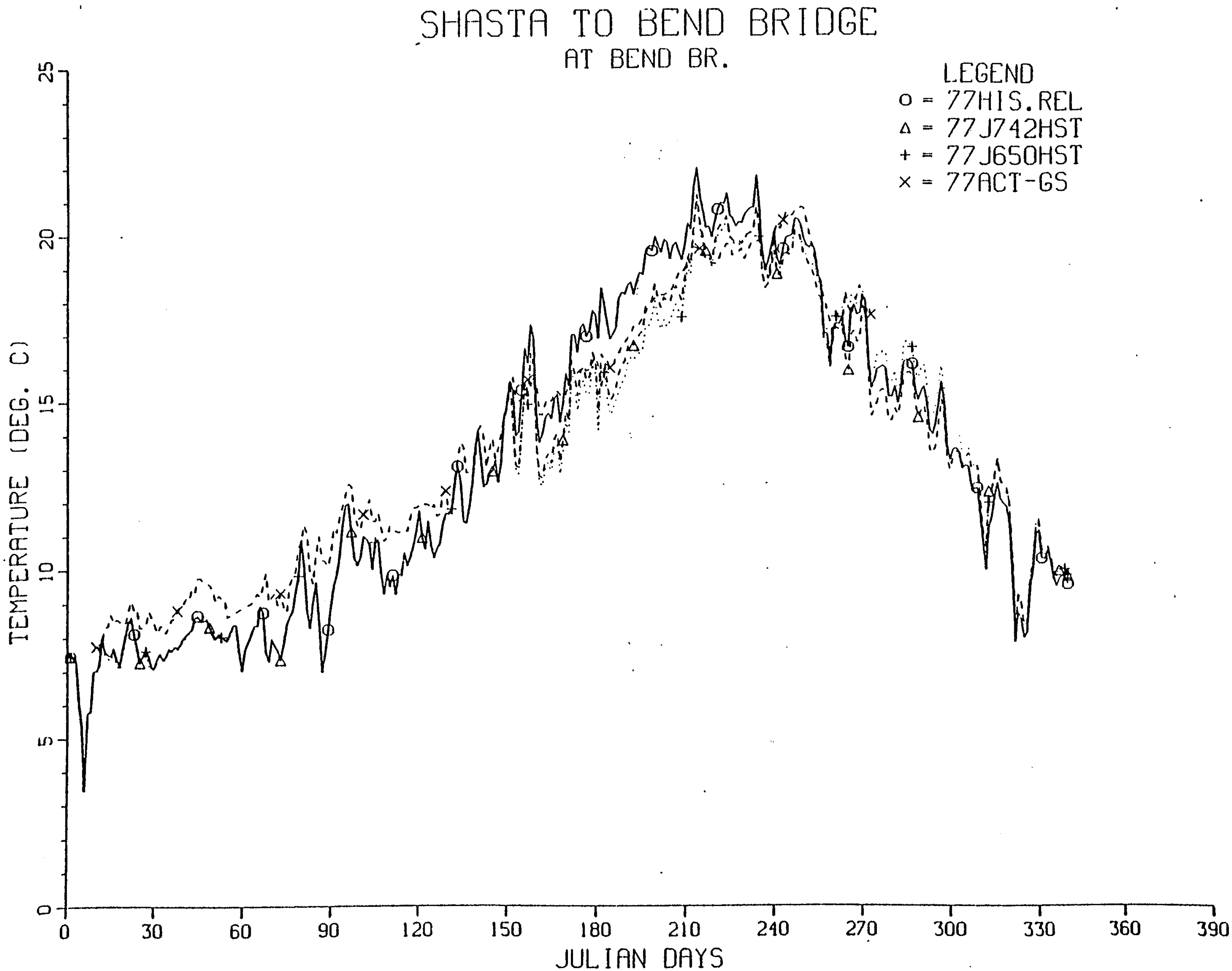

Figure 11. - 1977 Temperatures for Measued and Historic Data and Modified

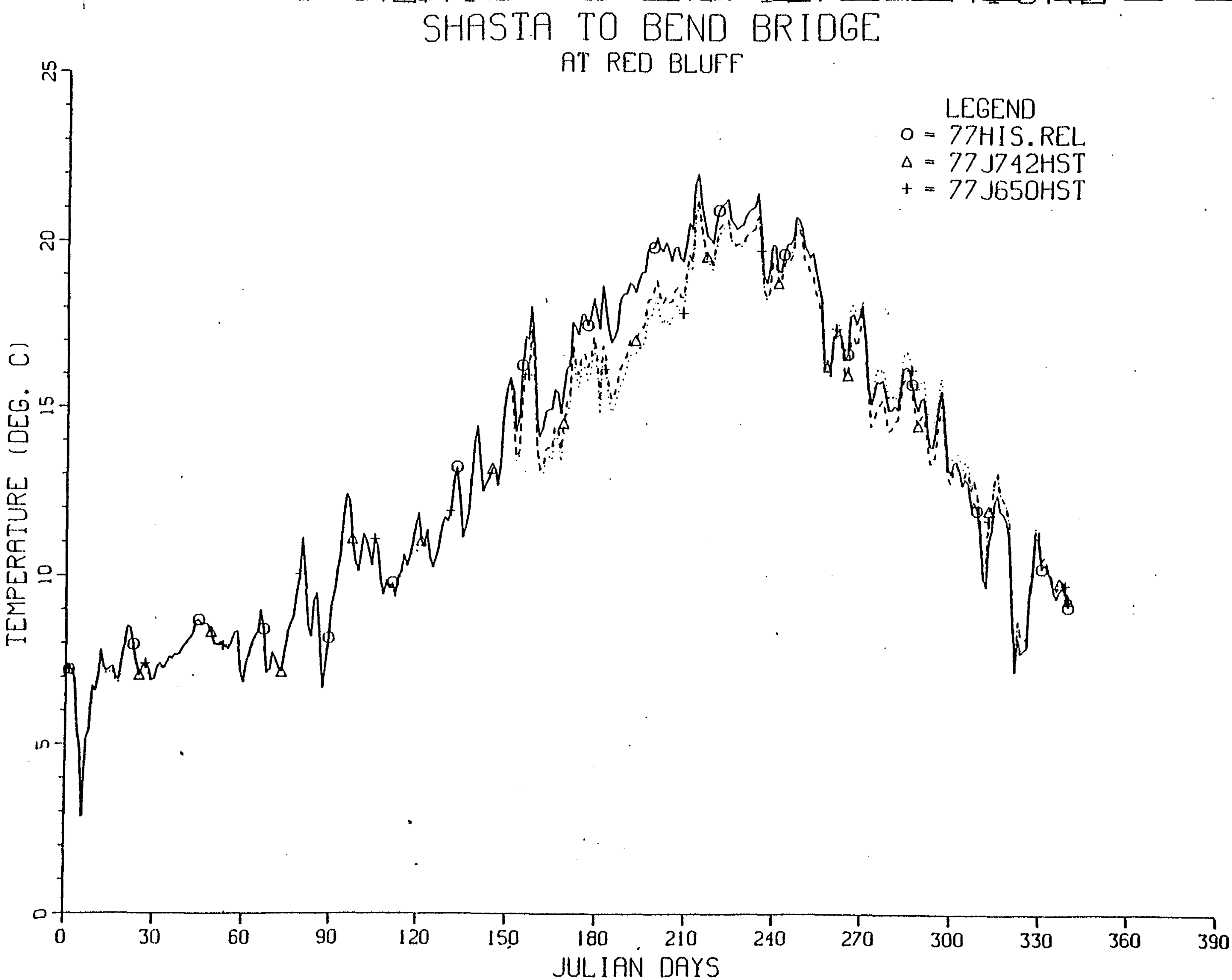

Figure 12. - 1977 Temperatures for Historic Data and Modified Releases for 650- and 742-foot elevations, at Red Bluff

[redacted]

SHASTA TO BEND BRIDGE

ABOVE CLEAR CR.

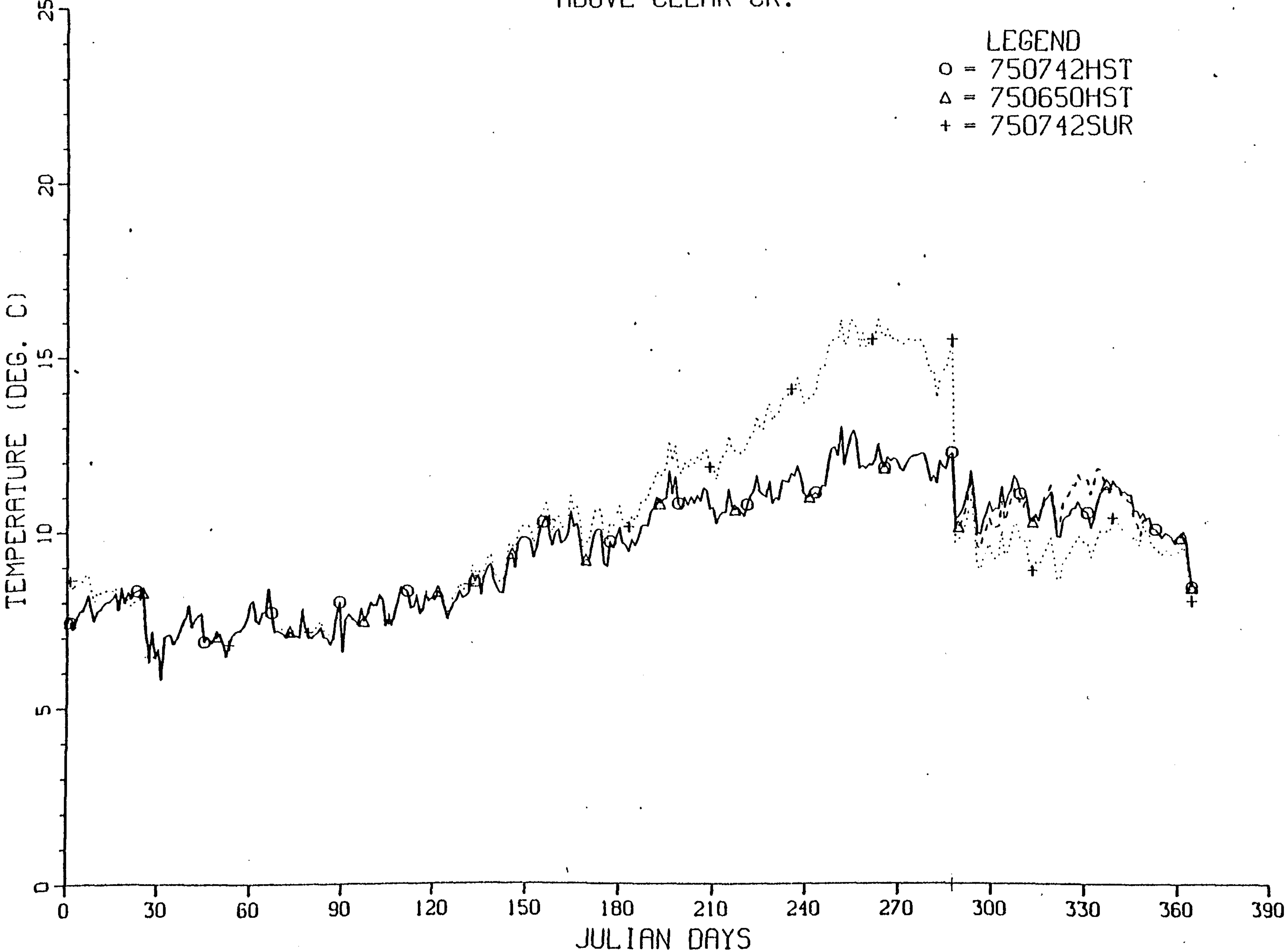

Figure 13. - 1975 Temperatures for 15 October Modified Releases for 650- and 742 feet elevations, above Clear Creek

[redacted]

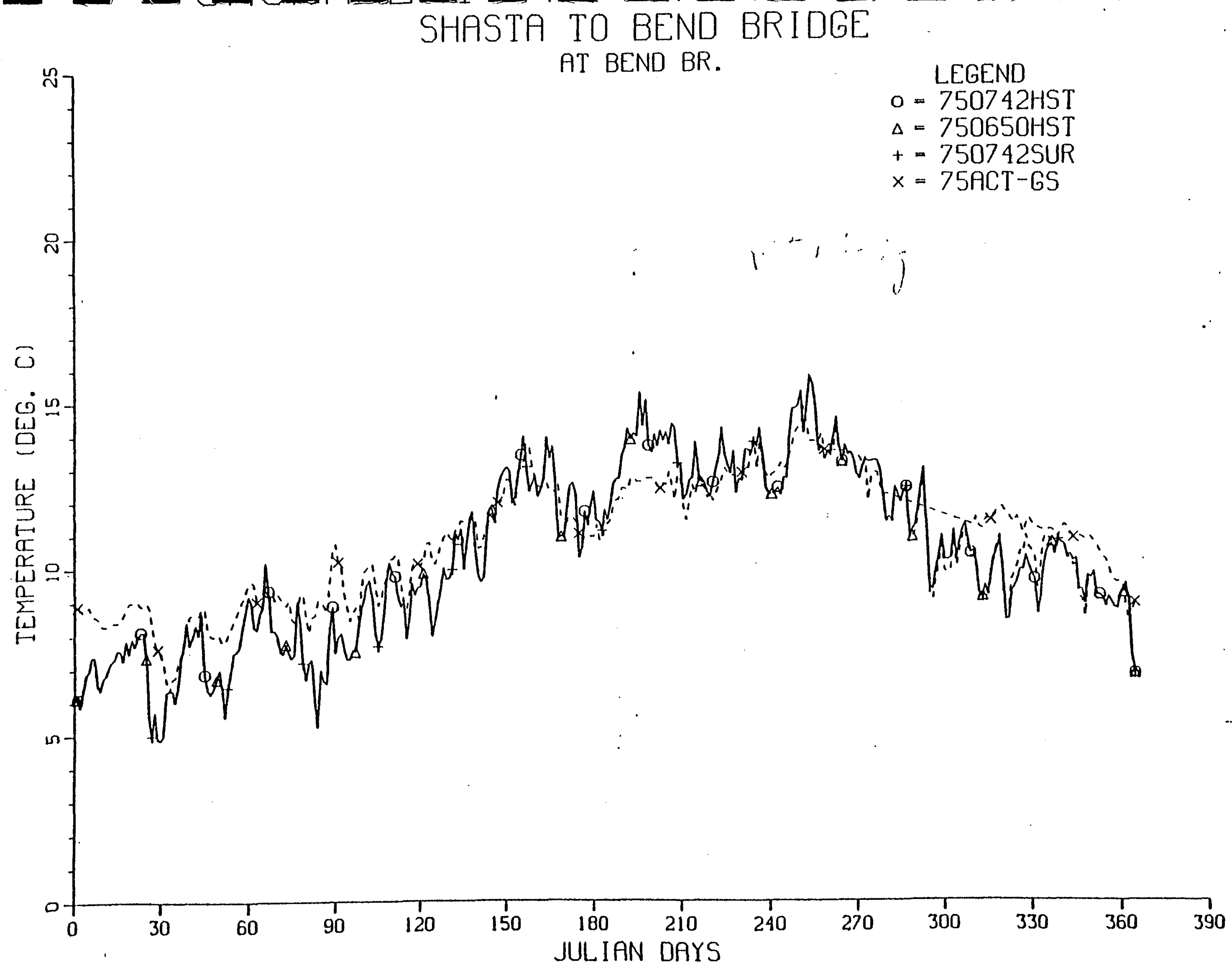

Figure 14. - 1975 Temperatures for Measured Data and 15 October Modified Releases
for 650 and 742 foot elevations at Bend Bridge

C-044579

C-044579

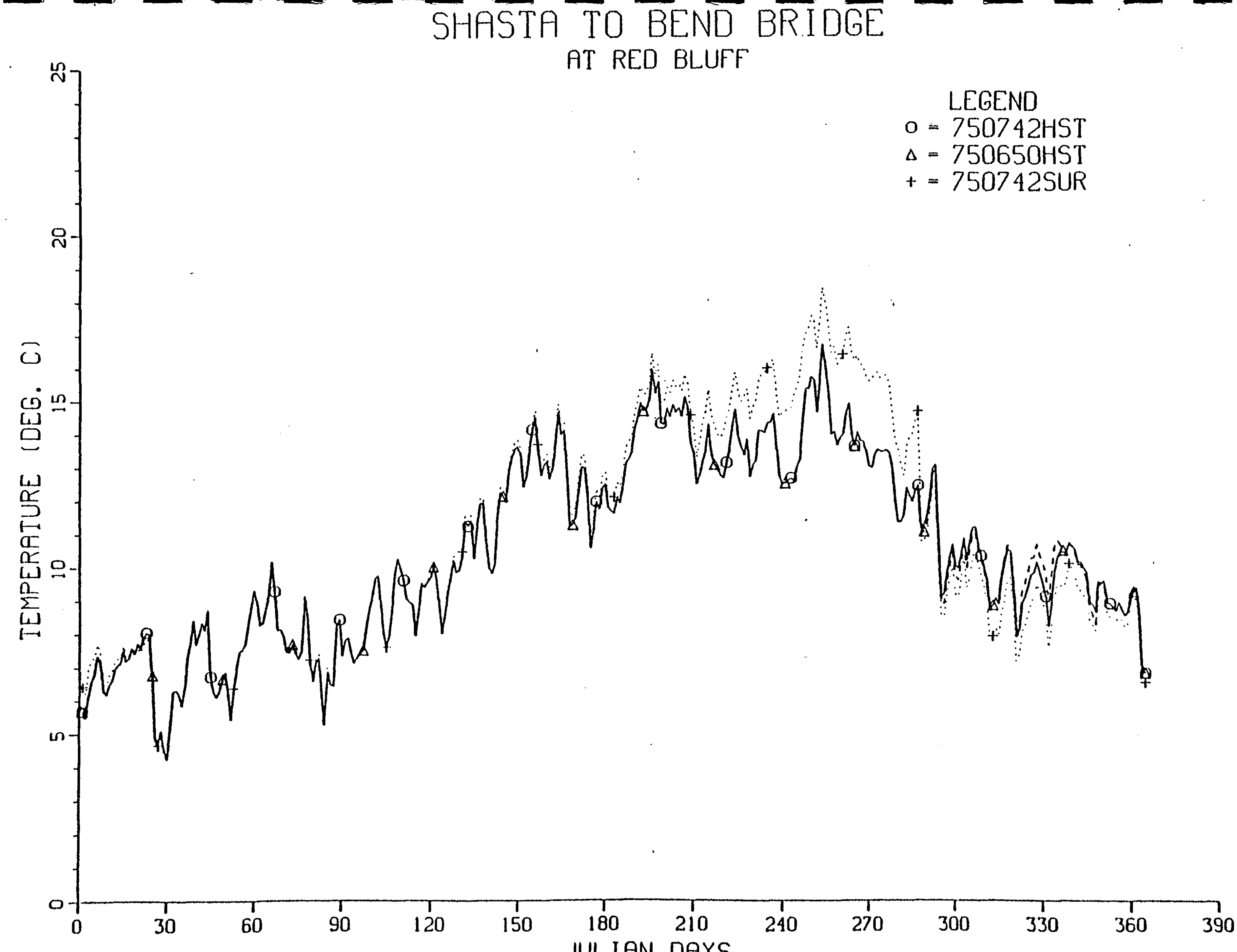

Figure 15. - 1975 Temperatures for 15 October Modified Releases for 650- and 742-foot elevations at Red Bluff

[redacted]

SHASTA TO BEND BRIDGE

ABOVE CLEAR CR.

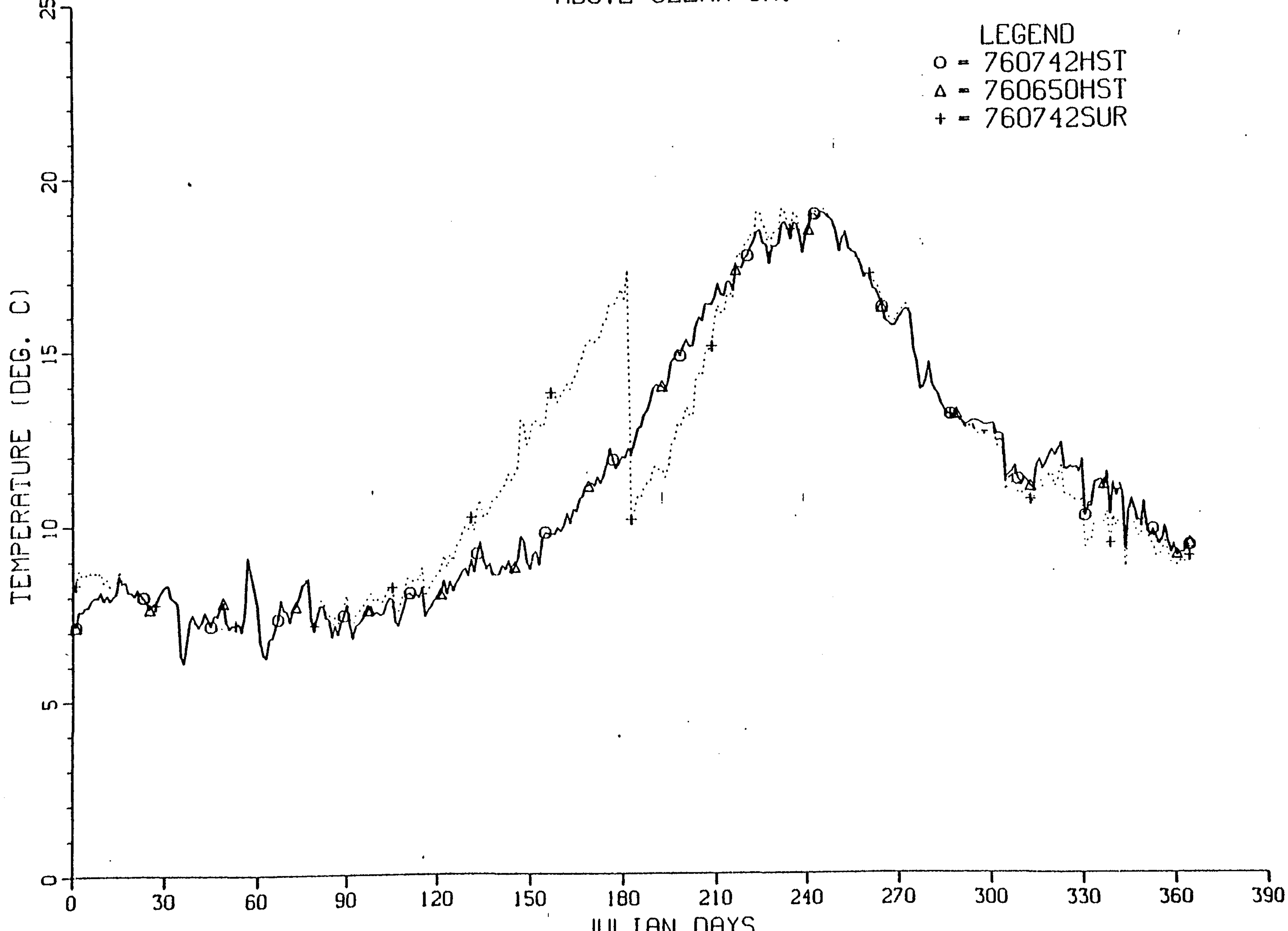

Figure 16. - 1976 Temperatures for 15 October Modified Releases for

[redacted]

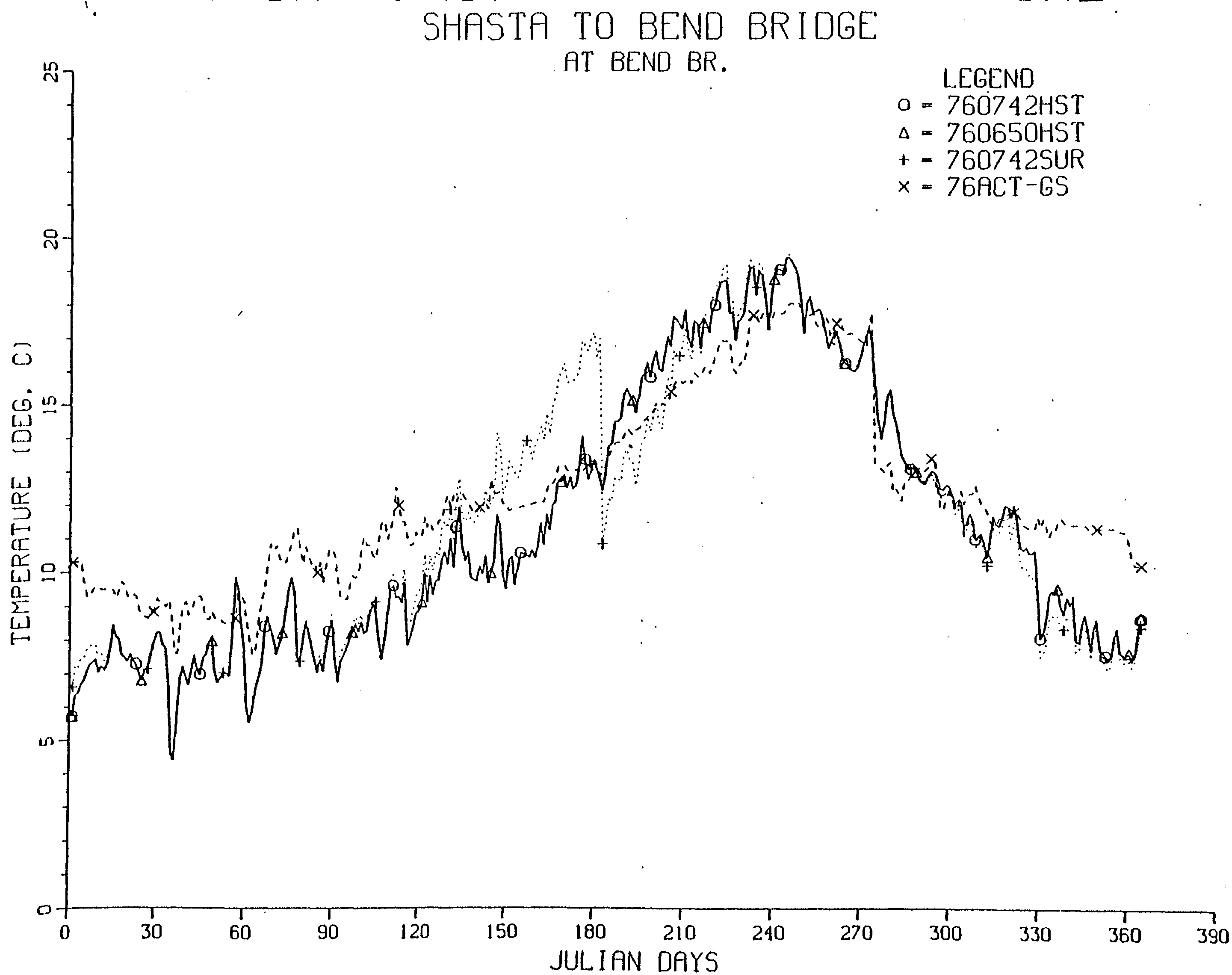

Figure 17. - 1976 Temperatures for Measured Data and 15 October Modified

C—044582

C-044582

C-044583

C—044583

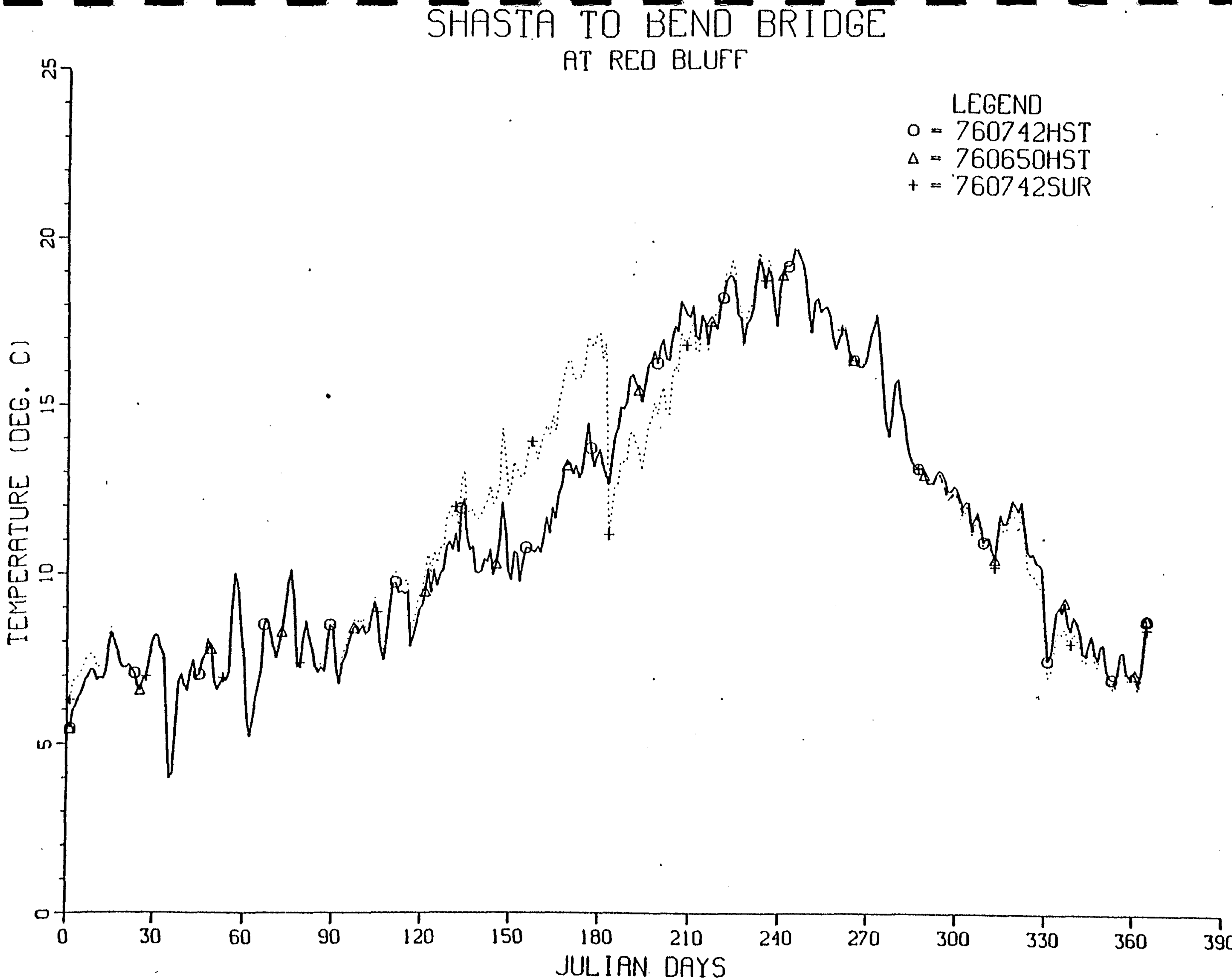

Figure 18. - 1976 Temperatures for 15 October Modified Releases for 650- and 742-foot elevations at Red Bluff

[redacted]

SHASTA TO BEND BRIDGE

ABOVE CLEAR CR.

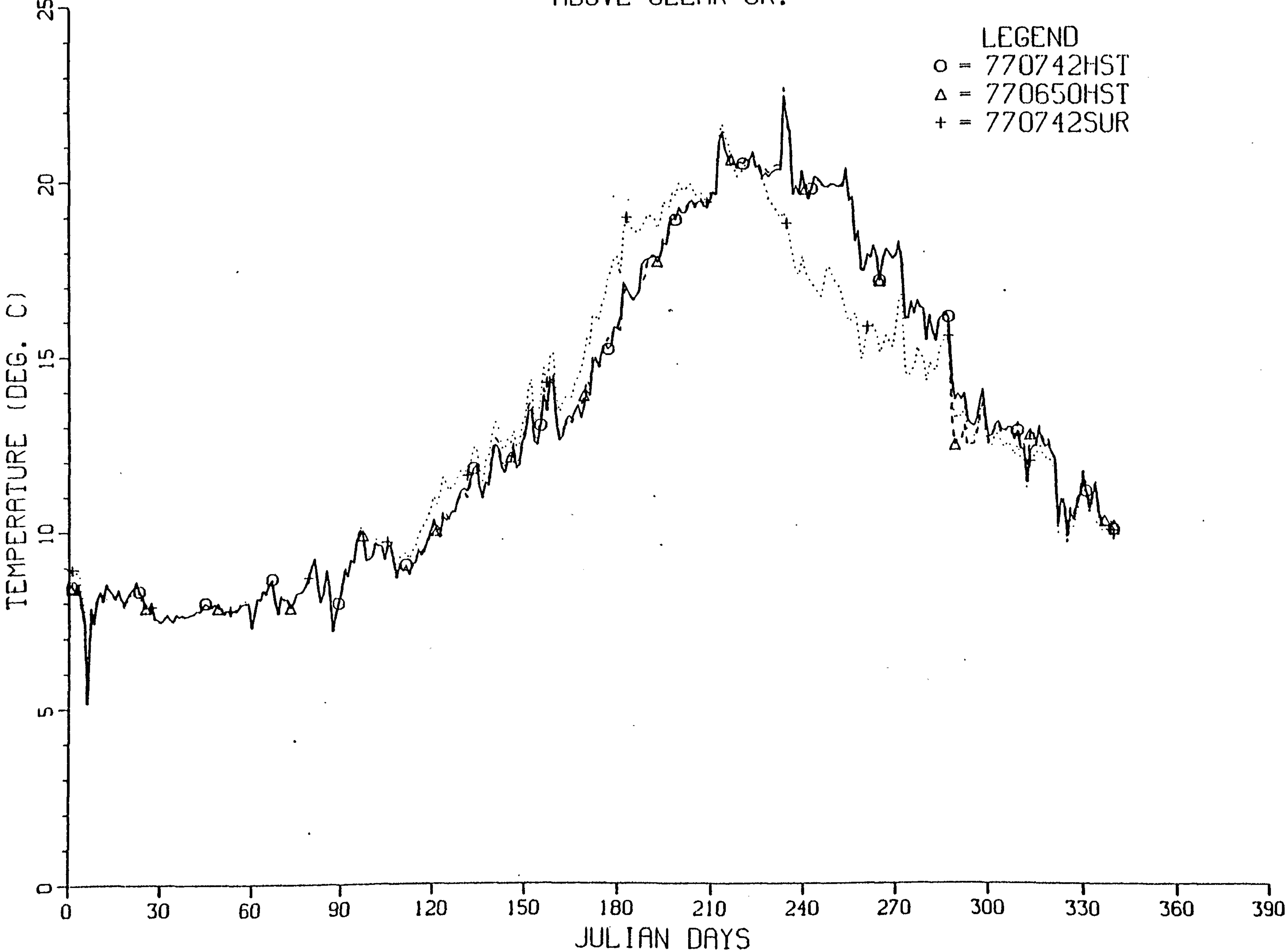

Figure 19. - 1977 Temperatures for 15 October Modified Releases for

C-044584

[redacted]

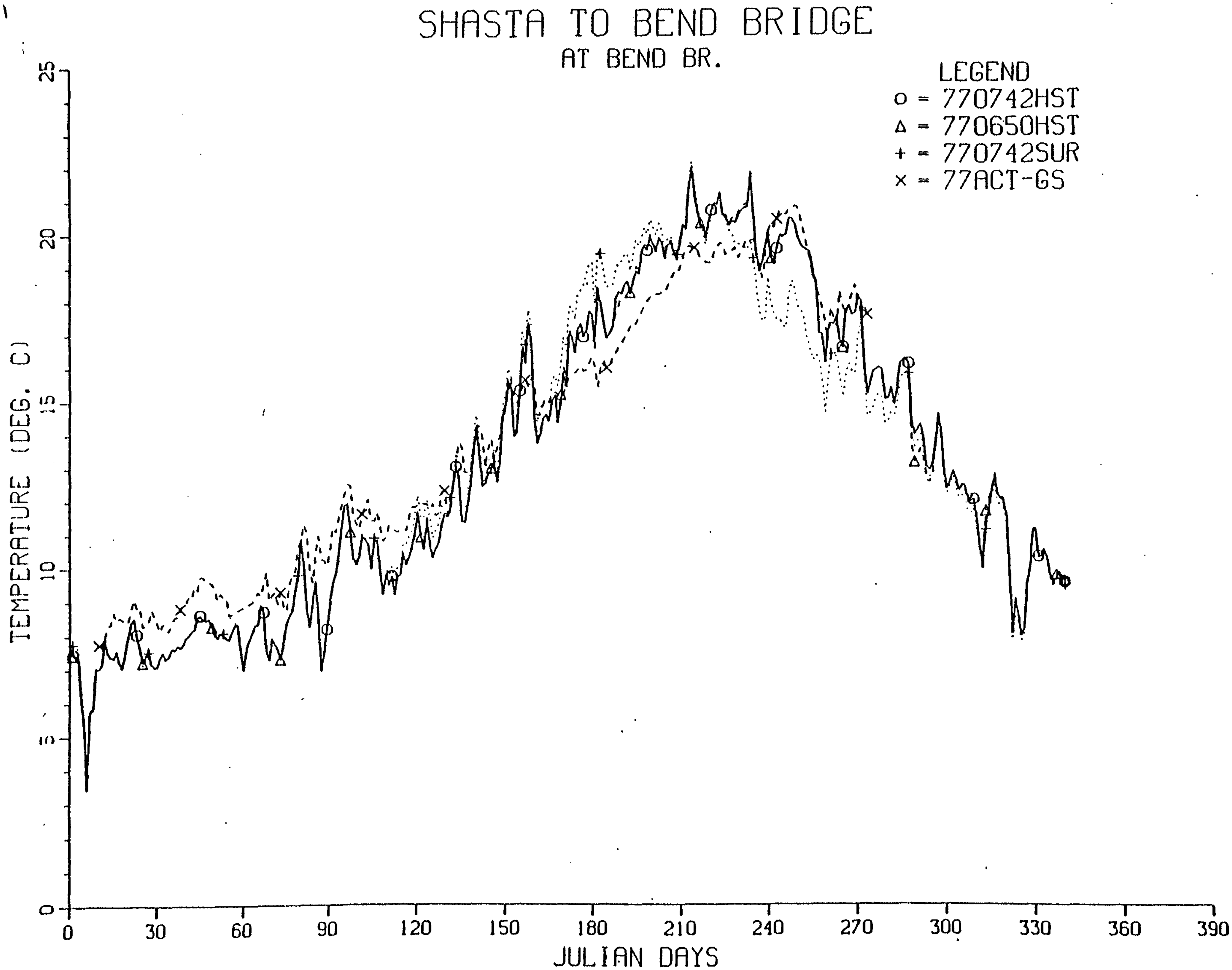

Figure 20. - 1977 Temperatures for Measured Data and 15 October Modified Releases

[redacted]

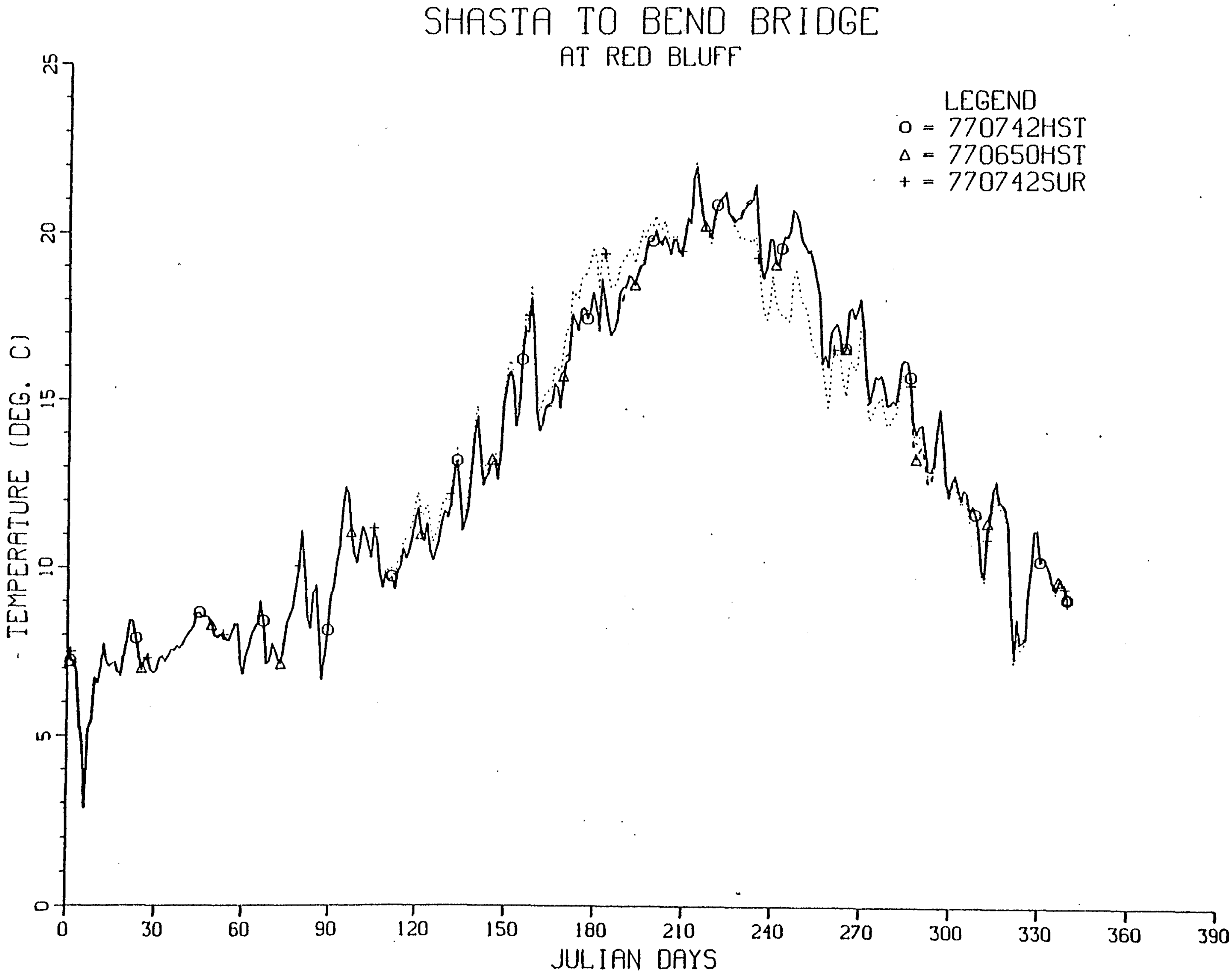

Figure 21. - 1977 Temperatures for 15 October Modified Releases for 650- and 742-foot elevations at Red Bluff

Comparison of figures 10 and 19 show that 2 or 3 °C cooler temperatures were obtained with surface releases than with historic releases. The temperature difference between the two conditions is less than 1 °C at Bend Bridge and Red Bluff because of the impact on solar heating between Clear Creek to Red Bluff or Bend Bridge. Consequently, most of the temperature changes caused by different operations are nearly damped out by the time the water gets to Bend Bridge.

Withdrawals from the deepest part of the reservoir obtain cooler water, but use up all the cold water by about September. The cold water can be kept in the reservoir by releasing water at or near the surface until fall when deeper cold water can be used to reduce the release temperature. However, the temperature returns to the historical conditions as the water flows downstream and is within 1 °C for all conditions at Bend Bridge.

Surface withdrawals earlier in the year are the most effective way of obtaining cooler fall temperatures. However, temperatures 1 to 2 °C warmer occur during the summer period with the near surface withdrawals. If these higher temperatures are tolerable, then surface releases followed by 742-foot releases are recommended as the best way of reducing the river temperature during the fall. If the summer temperatures are too high, then historical releases until June followed by 742-foot releases would be the next best alternative.

APPENDIX C

APPENDIX C

Salmon Benefit Summary
( ) Pre-1970 Spawning Distribution

Year	Alt.[1]	Fall	Late-Fall	Winter	Spring	Total[4]
1974	H	8.0 (4.0)	7.8	8.2	11.5	8.3 (5.8)
(Wet - 99%)[2]	1	7.3 (3.1)	7.3	7.5	9.2	7.5 (4.9)
	2	6.4 (1.8)	7.5	6.5	5.4	6.5 (3.6)
	3	6.4 (1.8)	7.5	6.4	5.5	6.5 (3.6)
1975	H	21.9 (18.7)	10.9	7.9	13.1	17.3 (15.3)
(Normal - 63%)	1	21.5 (18.2)	10.7	7.6	11.7	16.9 (14.9)
	2	17.4 (13.7)	10.4	6.7	9.4	14.0 (11.7)
	3	17.4 (13.7)	10.4	6.8	9.6	14.0 (11.7)
1976	H	35.2 (31.1)	35.6	62.7	57.0	41.9 (39.4)
(Dry - 12%)	1	35.2 (30.4)	33.1	55.5	65.4	41.0 (38.1)
	2	32.1 (25.6)	28.6	38.6	70.2	35.8 (31.8)
	3	31.1 (24.1)	29.1	44.3	70.5	36.3 (32.0)
1977	H	30.8 (29.2)	39.8	65.8	52.3	39.9 (39.0)
(Critical - 1%)	1	32.1 (31.3)	34.1	60.7	53.5	39.2 (38.7)
	2	31.6 (31.1)	32.5	60.2	53.8	38.7 (38.3)
	3	30.4 (28.9)	33.0	62.8	52.6	38.4 (37.4)
		Salmon Benefits - %[3]				
1974	1	.7 (.9)	.5	.7	2.3	.8 (.9)
	2	1.6 (2.2)	.3	1.7	6.1	1.8 (2.2)
	3	1.6 (2.2)	.3	1.8	6.0	1.8 (2.2)
1975	1	.4 (.5)	.2	.3	1.4	.4 (.4)
	2	4.5 (5.0)	.5	1.2	3.7	3.3 (3.6)
	3	4.5 (5.0)	.5	1.1	3.5	3.3 (3.6)
1976	1	0 (.7)	2.5	7.2	-8.4	.9 (1.3)
	2	3.1 (5.5)	7.0	24.1	-13.2	6.1 (7.6)
	3	4.1 (7.0)	6.5	18.4	-13.5	5.6 (7.4)
1977	1	1.3 (-2.1)	5.7	5.1	-1.2	.7 (.3)
	2	.8 (-1.9)	7.3	5.6	-1.5	1.2 (.7)
	3	.4 (.3)	6.8	3.0	-.3	1.5 (1.6)

[1] H - Historical - 815'
1 - Diversion Tunnel - 650', 815'
2 - Diversion Tunnel + MLO - 650', 742' - 1050'
3 - MLO - 742' - 1050'

[2] % years drier (1906-81)

[3] Historical loss - (Alt. loss)

[4] Weighted - (F - 61.4%, LF - 12.6%, W - 18.1%, S - 7.9%)

Temperature Model Results - 1976 (Dry)

Post Red Bluff Diversion Dam Spawning Distribution

Location	Alt.	J	F	M	A	M	J	J	A	S	O	N	D	
		MEAN MONTHLY TEMPERATURE - °F												
Keswick	H	46.9	45.2	45.2	45.3	46.7	50.3	56.6	62.5	61.9	56.0	53.8	51.6	
	1	46.9	45.2	45.2	45.3	46.7	50.2	52.6	60.8	61.7	55.8	54.0	53.3	
	2	47.6	45.7	46.1	47.3	50.1	51.4	51.8	56.4	61.5	55.8	53.4	54.2	
	3	47.6	45.7	46.1	47.3	50.1	51.4	51.9	58.3	61.1	55.7	54.0	53.1	
Cottonwood	H	45.3	44.8	45.6	46.6	49.6	52.8	59.2	63.3	62.9	56.6	52.5	47.3	
	1	45.3	44.8	45.6	46.6	49.6	52.8	56.1	61.9	62.7	56.5	52.6	48.3	
	2	45.7	45.0	46.1	47.9	52.2	53.7	55.4	58.5	62.5	56.5	52.2	48.9	
	3	45.7	45.0	46.1	47.9	52.2	53.7	55.5	60.0	62.3	56.5	52.6	48.2	
Red Bluff	H	44.7	44.6	45.8	47.2	51.1	54.1	60.5	63.6	63.1	56.6	51.7	45.7	
	1	44.7	44.6	45.8	47.2	51.1	54.1	57.8	62.4	63.0	56.4	51.8	46.5	
	2	45.1	44.8	46.2	48.3	53.2	54.8	57.2	59.5	62.8	56.4	51.5	46.9	
	3	45.1	44.8	46.2	48.3	53.2	54.8	57.3	60.8	62.6	56.4	51.8	46.4	
Spawning Run		TEMPERATURE-RELATED SALMON LOSSES - %												TOTAL
Fall	H	.7	6.4	3.5	1.1	.8	0	0	3.1	17.0	2.2	0	.4	35.2
	1	.9	6.9	3.6	1.1	.7	0	0	3.1	16.5	2.1	0	.3	35.2
	2	.5	4.8	3.1	.9	.6	.1	0	1.2	18.6	2.1	0	.2	32.1
	3	.6	4.9	3.2	.9	.6	0	0	2.8	15.8	2.1	0	.2	31.1
Late-Fall	H	.7	3.8	1.2	1.2	.2	.1	.1	11.8	1.2	.1	0	0	35.6
	1	.6	3.5	1.0	.2	.1	.1	1.9	21.2	4.3	.2	0	0	33.1
	2	.2	1.3	1.0	.1	0	.6	2.2	8.1	14.9	.2	0	0	28.6
	3	.2	1.5	.6	0	.1	.6	1.9	13.5	10.5	.2	0	0	29.1
Winter	H	0	0	.1	.1	0	.2	23.1	36.2	0	1.5	1.4	.1	62.7
	1	0	0	.1	.1	0	.2	2.2	47.8	2.0	1.5	1.5	.1	55.5
	2	0	0	0	0	0	.4	1.7	14.8	18.2	1.5	1.9	.1	38.6
	3	0	0	0	0	0	.4	1.3	24.8	14.6	1.5	1.6	.1	44.3
Spring	H	0	0	0	0	0	0	15.5	33.7	7.7	.2	0	0	57.0
	1	0	0	0	0	0	0	2.2	52.8	10.2	.2	0	0	65.4
	2	0	0	0	0	0	0	1.6	19.4	49.2	0	0	0	70.2
	3	0	0	0	0	0	0	1.4	39.7	29.4	0	0	0	70.5
Total	H													41.9
	1													41.0
	2													35.8
	3													36.3

Temperature Model Results - 1977 (Critical)

Post Red Bluff Diversion Dam Spawning Distribution

Location	Alt.	MEAN MONTHLY TEMPERATURE - °F											
		J	F	M	A	M	J	J	A	S	O	N	D
Keswick	H	47.3	46.0	46.9	48.5	52.0	55.4	63.1	67.5	65.1	59.4	53.6	50.9
	1	47.3	46.0	46.9	48.5	51.6	51.8	58.2	67.2	65.5	59.9	55.5	53.2
	2	47.6	46.5	47.3	49.2	51.3	51.8	57.4	67.2	65.5	59.9	55.5	53.2
	3	47.6	46.5	47.3	49.2	51.3	52.1	59.3	66.9	65.0	59.3	55.1	52.4
Cottonwood	H	45.1	46.0	46.6	50.2	53.4	59.2	64.5	67.7	64.3	58.3	51.6	49.4
	1	45.1	46.0	46.6	50.2	53.1	56.7	60.9	67.5	64.5	58.5	52.7	50.9
	2	45.2	46.5	46.8	50.7	52.9	56.7	60.3	67.5	64.5	58.5	52.7	50.9
	3	45.2	46.5	46.8	50.7	52.9	56.9	61.7	67.3	64.3	58.3	52.5	50.5
Red Bluff	H	44.2	46.3	46.9	51.3	54.3	61.3	65.4	67.9	64.1	58.1	50.7	49.0
	1	44.2	46.3	46.9	51.3	54.2	59.2	62.3	67.8	64.2	58.3	51.5	50.1
	2	44.4	46.7	47.0	51.7	54.0	59.2	61.8	67.8	64.2	58.3	51.5	50.1
	3	44.4	46.7	47.0	51.7	54.0	59.4	63.0	67.6	64.0	58.1	51.4	49.8

Spawning Run		TEMPERATURE-RELATED SALMON LOSSES - %												TOTAL
Fall	H	1.1	.4	1.0	.8	.8	0	0	3.1	18.6	4.4	.1	.4	30.8
	1	1.4	.4	1.0	.9	.5	0	0	3.1	18.6	5.8	.2	.3	32.1
	2	1.2	.3	.8	.9	.5	0	0	3.1	18.6	5.8	.2	.3	31.6
	3	1.4	.3	.7	.9	.6	0	0	3.1	18.6	4.3	.2	.3	30.4
Late-Fall	H	1.5	0	.1	0	.8	14.1	21.1	1.6	.1	0	.3	.2	39.8
	1	1.6	.2	.1	0	.5	5.3	15.6	9.7	.7	0	.2	.2	34.1
	2	1.7	.2	.1	0	.6	5.4	13.3	10.2	.7	0	.2	.2	32.5
	3	1.6	.1	0	0	.6	5.8	17.8	6.3	.4	0	.2	.2	33.0
Winter	H	0	0	0	0	.2	14.5	49.3	.4	0	.1	1.3	0	65.8
	1	0	0	0	0	.1	3.8	39.1	16.6	0	.1	1.0	0	60.7
	2	0	0	0	0	.2	3.8	35.1	20.1	0	.1	10	0	60.2
	3	0	0	0	0	.2	4.3	48.1	9.0	0	.1	1.1	.1	62.8
Spring	H	0	0	0	0	0	0	27.9	18.3	5.0	1.1	0	0	52.3
	1	0	0	0	0	0	0	23.1	23.8	5.4	1.2	0	0	53.5
	2	0	0	0	0	0	0	21.8	25.4	5.5	1.2	0	0	53.8
	3	0	0	0	0	0	0	25.3	20.7	5.6	1.0	0	0	52.6
Total	H													39.9
	1													39.2
	2													38.7
	3													38.4

APPENDIX D

1980 LEVEL		2020 LEVEL		ALT.	FLOW CONDITION - CFS		
OP. STUDY	DATE	OP. STUDY	DATE		WET & NORMAL	DRY	CRITICAL
A1A	9/18/85	A1F	9/16/85	BASE	EXIST. *	EXIST.	EXIST.
A1B	9/26/85	A1J	9/17/85	1	6000	6000	4500
A1E	10/8/85	A1G	9/17/85	2	6000	4500	4500
A1C	9/27/85	A1H	9/16/85	3	6000	4500	EXIST.
A1D	9/18/85	A1I	9/16/85	4	6000	EXIST.	EXIST.

* EXISTING AGREEMENT W/DFG FOR KESWICK FLOWS - 4/5/60 →

MONTH	WET, NORMAL, & DRY	CRITICAL
JAN-FEB	2600	2000
MAR-AUG	2300	2300
SEPT-NOV	3900	2800
DEC	2600	2000

COMPUTATION SHEET

BY Trowell DATE 10/18/85
CHKD BY DATE
PROJECT CVFWMS - A-1
FEATURE 760 OPERATION STUDIES
DETAILS FISHERY FLOW ALTERNATIVES
SHEET 1 OF 7

APPENDIX D

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BY	DATE	PROJECT	SHEET
Rowell	10/18/85	CVFWMS - A-1	2 OF 7
CHKD BY	DATE	FEATURE	
		TEMPERATURE - SALMON MORTALITY STUDY	
DETAILS		SACRAMENTO RIVER - POWER OPERATIONS STUDY	

1980 LEVEL

YEAR	ALT.	INITIAL SHASTA ELEV.-FT.	J	F	M	A	M	J	J	A	S	O	N	D
			SACRAMENTO RIVER FLOW BELOW KESWICK - CFS											
1923 (DRY)	B	1023.4	2602	2593	2456	2302	11124	11344	12897	8148	4638	3903	4672	5578
	1	997.5	6001	5996	6001	6000	7676	11445	12978	"	6000	6001	6000	6001
	2	995.3	"	"	4505	4504	"	"	"	"	5277	4505	6487	6603
	3	997.5	"	"	"	"	"	"	"	"	5210	"	4790	6944
	4	993.9	"	"	2537	2302	11092	11310	12848	"	4840	3903	4622	5871
1931 (CRITICAL)	B	977.0	4001	2593	4944	7260	5692	6016	7676	6522	6974	3919	5243	3301
	1	883.0	6001	5996	4505	"	"	"	"	"	6537	4505	4638	4505
	2	906.4	"	"	"	"	"	"	"	"	6857	"	"	"
	3	903.6	"	"	3188	"	"	"	"	"	6974	3919	5243	2082
	4	915.5	"	"	"	"	"	"	"	"	"	"	"	"
1934 (CRITICAL)	B	978.9	3301	1999	4228	5193	6554	6184	7741	6473	5764	3741	2807	4781
	1	794.9	4505	4501	4505	"	7221	"	"	"	"	4505	4504	4505
	2	850.4	"	"	"	"	"	"	"	"	"	"	"	"
	3	905.5	2000	1999	4245	"	6554	"	"	"	"	3741	2807	4781
	4	919.7	"	"	"	"	"	"	"	"	"	"	"	"
1954 (NORMAL)	B	1023.2	15857	21121	9449	13461	10506	12302	14165	8538	6201	4391	11898	6928
	1	1018.9	14182	"	"	"	"	11949	14178	"	6000	6001	10756	"
	2	1018.9	"	"	"	"	"	11915	14165	"	6302	"	10503	"
	3	1018.9	"	"	"	"	"	"	"	"	"	"	"	"
	4	1018.9	"	"	"	"	"	"	"	"	"	"	"	"
1958 (WET)	B	1022.1	18996	49138	23062	14907	9872	11898	9482	7806	4924	14442	15780	4619
	1	1022.1	18215	50003	"	"	"	"	"	"	6000	13401	"	6001
	2	1022.1	"	"	"	"	"	"	"	"	"	"	"	"
	3	1022.1	"	"	"	"	"	"	"	"	"	"	"	"
	4	1022.1	"	"	"	"	"	"	"	"	"	"	"	"

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COMPUTATION SHEET

★ U.S. Government Printing Office: 1977-779-651

BY	DATE	PROJECT CVFWMS - A-1	SHEET 3 OF 7
CHKD BY	DATE	FEATURE TEMPERATURE STUDY	
DETAILS		POWER OPERATION	

1980 LEVEL

YEAR	ALT.	J	F	M	A	M	J	J	A	S	O	N	D
		SACRAMENTO RIVER TEMPERATURES AT RED BLUFF - °F											
1923	B	43.3	44.3	46.3	49.6	51.3	53.1	56.6	58.8	60.5	56.3	51.7	48.0
	1	44.8	45.0	45.9	48.0	52.7	53.5	58.7	62.4	62.8	59.3	54.1	48.4
	2	44.8	45.0	46.0	48.5	52.6	53.3	58.2	62.0	62.7	58.2	54.2	48.9
	3	44.8	45.0	46.0	48.5	52.6	53.3	58.0	61.7	62.4	58.0	53.0	49.1
	4	44.8	45.0	46.3	49.6	51.3	53.4	58.3	61.5	62.2	57.5	52.6	48.4
1931	B	44.1	47.4	46.9	51.1	53.2	61.2	61.3	64.2	61.8	58.1	52.2	50.5
	1	44.1	45.9	46.8	52.5	55.8	65.8	63.6	67.7	64.3	58.4	50.7	48.8
	2	44.5	46.1	46.7	51.7	55.2	64.5	66.5	68.2	64.3	58.6	51.2	49.6
	3	44.5	46.1	46.8	51.6	55.0	64.1	66.1	68.1	64.3	58.4	51.3	48.6
	4	44.7	46.3	46.8	51.4	54.6	63.6	65.7	68.0	64.5	58.5	51.2	48.8
1934	B	43.7	44.1	45.9	48.2	53.2	55.8	59.6	59.3	58.8	55.5	50.7	46.9
	1	43.3	43.7	45.8	48.8	55.6	60.1	67.0	61.6	63.3	58.2	51.5	44.5
	2	43.6	43.9	45.7	48.4	54.2	58.5	65.3	65.1	64.0	58.6	52.0	45.2
	3	42.8	43.9	45.7	48.1	53.3	56.2	60.8	61.4	62.0	57.3	51.1	47.0
	4	42.8	44.0	45.8	48.1	53.2	56.1	60.4	60.6	61.1	57.6	51.0	47.1
1954	B	45.7	45.4	46.2	47.5	52.8	54.3	55.9	58.5	58.6	53.5	51.0	48.1
	1	45.5	45.4	46.2	47.5	52.9	54.4	55.8	58.5	58.7	53.5	50.7	48.1
	2	45.5	45.4	46.2	47.5	52.7	54.5	55.9	58.5	58.5	53.5	50.7	48.1
	3	"	"	"	"	"	"	"	"	"	"	"	"
	4	"	"	"	"	"	"	"	"	"	"	"	"
1958	B	46.0	46.4	47.5	49.0	52.7	55.5	58.6	59.3	58.7	54.1	53.7	46.3
	1	46.0	46.5	47.5	49.0	52.7	55.5	58.6	59.3	58.0	54.2	53.7	47.3
	2	"	"	"	"	"	"	"	"	"	"	"	"
	3	"	"	"	"	"	"	"	"	"	"	"	"
	4	"	"	"	"	"	"	"	"	"	"	"	"

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BY	DATE	PROJECT CVFWMS A-1	SHEET 4 OF 7
CHKD BY	DATE	FEATURE TEMPERATURE STUDY	
DETAILS		POWER OPERATION	

1980 LEVEL

YEAR	ALT.	FALL	LATE-FALL	WINTER	SPRING	TOTAL	IMPAC
		SALMON LOSSES - %					
1923	B	33.7	14.5	13.0	32.2	27.4	
	1	39.1	29.3	47.6	63.8	41.3	-13.9
	2	36.0	27.6	45.6	62.5	38.8	-11.4
	3	34.5	26.1	41.5	59.7	36.7	-9.3
	4	33.0	23.4	38.2	55.5	34.5	-7.1
1931	B	27.6	28.3	40.8	55.1	32.3	
	1	33.0	52.5	56.7	53.6	41.4	-9.1
	2	33.3	46.6	62.8	52.7	41.9	-9.6
	3	32.7	44.6	63.5	52.6	41.3	-9.0
	4	33.5	42.0	63.5	52.7	41.5	-9.2
1934	B	31.9	15.3	12.5	21.2	25.4	
	1	40.7	55.4	67.8	60.6	49.0	-23.6
	2	41.9	49.0	68.1	55.1	48.6	-23.2
	3	39.3	32.7	34.6	52.3	38.6	-13.2
	4	38.5	26.1	24.1	43.7	34.8	-9.4
1954	B	8.8	8.3	8.0	15.2	9.1	
	1	9.0	8.9	8.2	15.7	9.4	-0.3
	2	8.8	8.6	7.9	14.5	9.1	0.0
	3	"	"	"	"	"	"
	4	"	"	"	"	"	"
1958	B	9.9	10.2	11.8	18.9	11.0	
	1	7.9	9.8	11.6	16.9	9.5	1.5
	2	7.9	9.8	11.6	16.9	9.5	1.5
	3	"	"	"	"	"	"
	4	"	"	"	"	"	"

* BASE - ALT.

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BY	DATE	PROJECT CVFWMS A-1	SHEET 5 OF 7
CHKD BY	DATE	FEATURE TEMPERATURE STUDY	
DETAILS		POWER OPERATION	

2020 LEVEL

YEAR	ALT.	INITIAL SHASTA ELEV.-FT.	J	F	M	A	M	J	J	A	S	O	N	D
			SACRAMENTO RIVER FLOW BELOW KESWICK - CFS											
1923	B	1023.4	2602	2593	2862	2302	11580	11999	13547	10273	6689	4765	6285	6310
	1	1018.8	6001	5996	6001	6000	10181	10302	12442	9384	6000	6001	6000	6001
	2	1018.8	"	"	4505	4504	10213	10305	12507	9351	4655	4505	4504	5204
	3	1018.8	"	"	"	"	"	"	"	"	"	"	"	"
	4	1018.8	"	"	2309	2302	10278	10386	12620	9417	4554	3903	3899	5774
1931	B	995.8	2602	3043	5904	10016	7432	6605	8441	6977	6571	5611	5579	2000
	1	976.1	6001	5996	4505	6420	4912	5512	8815	7270	5731	4505	5143	4505
	2	996.4	"	"	"	"	"	"	"	"	"	"	"	"
	3	923.8	"	"	3090	8604	6457	5865	7042	6196	5529	3806	5025	2000
	4	927.9	"	"	"	8688	6538	5966	7221	6310	5563	3838	5075	"
1934	B	855.1	2000	1997	2293	7983	7969	6806	8376	6847	6285	4960	3848	4440
	1	871.2	4505	4501	4505	6470	5383	4457	4879	7367	5563	4505	4504	4505
	2	906.5	"	"	"	"	"	"	"	"	"	"	"	"
	3	858.9	2000	1999	2293	7428	7302	6437	7676	6408	5428	3443	3664	4147
	4	860.1	"	"	"	"	"	"	"	"	"	"	3647	3985
1954	B	1023.2	15857	20741	9449	13377	11287	14839	13531	11108	8520	5286	3897	6372
	1	1019.7	14474	"	"	13374	10457	14150	13092	10470	6050	6001	7731	6961
	2	1019.7	"	"	"	"	"	"	"	"	"	"	"	"
	3	1019.7	"	"	"	"	"	"	"	"	"	"	"	"
	4	1019.7	"	"	"	"	"	"	"	"	"	"	"	"
1958	B	1022.1	19012	49066	23143	14940	9791	11814	13775	10116	7478	5302	15764	4196
	1	1022.1	18215	49949	"	14757	9807	11831	13255	9595	6000	7758	15780	6001
	2	1022.1	"	"	"	"	"	"	"	"	"	"	"	"
	3	1022.1	"	"	"	"	"	"	"	"	"	"	"	"
	4	1022.1	"	"	"	"	"	"	"	"	"	"	"	"

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BY	DATE	PROJECT CVFWMS A-1	SHEET 6 OF 7
CHKD BY	DATE	FEATURE TEMPERATURE STUDY	
DETAILS		POWER OPERATION	

2020 LEVEL

SACRAMENTO RIVER TEMPERATURES AT RED BLUFF – °F

YEAR	ALT.	J	F	M	A	M	J	J	A	S	O	N	D
1923	B	43.3	44.3	46.2	49.6	51.1	52.9	56.5	58.6	60.6	57.4	53.4	49.1
	1	44.9	45.1	46.0	48.1	51.7	53.8	57.8	60.3	61.8	58.3	53.8	48.8
	2	44.9	45.1	46.1	48.5	51.7	53.7	57.4	59.7	61.7	57.3	52.4	47.9
	3	"	"	"	"	"	"	"	"	"	"	"	"
	4	44.9	45.1	46.4	49.6	51.5	53.5	56.9	58.9	61.2	56.9	51.7	48.1
1931	B	42.9	47.4	47.0	50.4	52.6	60.8	61.1	64.5	63.0	59.0	52.3	49.5
	1	45.2	47.2	46.9	51.3	53.7	61.8	60.9	65.2	63.7	58.5	52.3	51.3
	2	45.2	47.5	47.0	51.4	53.6	61.6	60.2	63.5	62.4	58.2	52.4	51.5
	3	44.8	46.3	46.8	51.0	54.7	64.0	66.6	68.4	64.4	58.3	51.0	48.4
	4	44.8	46.4	46.8	50.9	54.5	63.8	66.4	68.3	64.2	58.2	50.9	48.4
1934	B	42.6	43.8	46.1	47.4	53.4	57.7	64.4	65.0	64.2	59.2	51.8	45.3
	1	43.6	43.9	45.7	48.0	54.8	58.4	64.4	63.0	63.3	58.6	52.8	45.7
	2	43.9	44.2	45.7	47.8	54.2	57.8	63.5	60.6	61.8	58.0	52.7	46.9
	3	42.6	43.8	46.1	47.5	53.4	57.3	63.6	64.2	63.7	58.1	52.1	46.1
	4	42.6	43.8	46.1	47.5	53.4	57.3	63.5	64.2	63.6	58.0	52.1	45.9
1954	B	45.7	45.4	46.2	47.5	52.5	53.5	56.2	57.6	58.3	54.5	48.1	47.8
	1	45.6	45.4	46.2	47.5	52.9	53.7	56.4	57.7	59.0	53.9	50.0	48.2
	2	"	"	"	"	"	"	"	"	"	"	"	"
	3	"	"	"	"	"	"	"	"	"	"	"	"
	4	"	"	"	"	"	"	"	"	"	"	"	"
1958	B	46.1	46.5	47.5	49.0	52.8	55.5	56.8	58.6	58.2	54.6	53.9	46.0
	1	46.0	46.5	47.5	49.0	52.8	55.5	57.0	58.7	58.5	54.7	53.8	47.4
	2	"	"	"	"	"	"	"	"	"	"	"	"
	3	"	"	"	"	"	"	"	"	"	"	"	"
	4	"	"	"	"	"	"	"	"	"	"	"	"

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BY	DATE	PROJECT CVFWMS A-1	SHEET 7 OF 7
CHKD BY	DATE	FEATURE · TEMPERATURE STUDY	
DETAILS		POWER OPERATION	

2020 LEVEL

		SALMON LOSSES - %					
YEAR	ALT.	FALL	LATE-FALL	WINTER	SPRING	TOTAL	IMPACT
1923	B	36.9	16.4	16.1	37.1	30.6	
	1	32.2	21.9	30.7	54.1	32.4	-1.8
	2	29.7	17.5	23.9	47.0	28.5	2.1
	3	"	"	"	"	"	"
	4	28.8	14.3	16.4	39.5	25.6	5.0
1931	B	33.9	31.7	47.6	60.9	38.3	
	1	31.3	31.4	51.9	59.1	37.2	1.1
	2	28.1	27.6	39.9	60.8	32.8	5.5
	3	32.4	44.3	64.0	52.3	41.2	-2.9
	4	31.9	43.2	64.0	52.3	40.7	-2.4
1934	B	42.6	48.4	67.7	55.4	48.9	
	1	42.0	44.0	50.7	60.1	45.3	3.6
	2	38.1	32.8	33.8	50.2	37.6	11.3
	3	42.2	46.4	64.5	56.3	47.9	1.0
	4	41.9	46.1	64.5	56.4	47.7	1.2
1954	B	10.0	7.7	7.3	13.2	9.5	
	1	9.3	8.6	7.8	16.2	9.5	0.0
	2	"	"	"	"	"	"
	3	"	"	"	"	"	"
	4	"	"	"	"	"	"
1958	B	10.6	8.3	8.5	16.2	10.3	
	1	9.0	8.5	8.9	15.8	9.4	0.9
	2	"	"	"	"	"	"
	3	"	"	"	"	"	"
	4	"	"	"	"	"	"

* BASE - ALT.

APPENDIX E

Appendix E

Report of the U.S. Fish and Wildlife Service on Problem A-1, Reservoir Fishery Evaluation

Introduction

Purpose and Scope

The results of a special analysis made as part of the Central Valley Fish and Wildlife Management Study are presented in this report. An analysis is presented of the impacts to the reservoir fishery that occurs with existing reservoir operation schedules, or would occur with alternative operation schedules for three Central Valley reservoirs including Clair Engle, Folsom and Shasta.

Operation schedules developed for selected water years representing all years of record (1922-1970), dry (1923), critical (1931 and 1934), normal (1954) and wet (1958) years were analyzed. Data on 1980 and 2020 levels of water development were used in the analysis. Impacts to the reservoir fisheries under the various alternatives are identified and findings and conclusions are reported.

C-044601

Clair Engle Lake lies at the base of the Trinity Alps and has relatively steep sides. Vegetation along the 145-mile shoreline is primarily coniferous forest. Precipitation averages about 50 inches annually.

Irrigation, recreation, and power production are authorized purposes of Clair Engle Lake. The Trinity Powerplant has a rated capacity of 105,556 Kw.

The reservoir supports both warm and coldwater fisheries. A list of fish species presently found in Clair Engle Lake is presented in Table 1. The coldwater fishery is supported by rainbow trout, brown trout, and kokanee. About 80,000 rainbow trout are planted annually to sustain a put-and-take fishery. The brown trout and kokanee sustain themselves naturally through reproduction in tributaries to the reservoir.

Warmwater species at the reservoir are self-sustaining. Smallmouth bass, largemouth bass, green sunfish, white catfish, and brown bullhead are harvested. Smallmouth bass support high angler interest since the California State record for smallmouth bass was caught in Clair Engle Lake.

Lack of cover habitat is recognized as a physical factor which limits centrarchid production.

Recreational activities at the reservoir include powerboating, fishing, camping, houseboating, swimming, and water skiing. Six resorts and/or

Table 1. Fish species occurring in Clair Engle, Folsom and Shasta Lake today.[1/]

Fish Species		Clair Engle	Folsom	Shasta
White sturgeon [2/]	*Acipenser transmontanus*		X	X
Threadfin shad	*Dorosoma petenense*		X	X
Silver salmon	*Oncorhynchus kisutch*			X
Kokanee salmon	*Oncorhynchus nerka*	X	X	X
Rainbow trout/steelhead	*Salmo gairdnerii*	X		
Kamloops trout	*Salmo gairdnerii kamloops*			X
Lahontan cutthroat trout	*Salmo clarki*			X
Brown trout	*Salmo trutta*	X	X	X
Dolly Varden trout [2/]	*Salvelinus sp.*			X
Brook trout	*Salmo fontinalis*			X
Speckled dace	*Rhinichthys osculus*	X		
Hitch	*Lavinia exilicauda*		X	
Tui chub	*Gila bicolor*			X
Sacramento blackfish	*Orthodon microlepidotus*			X
Hardhead	*Mylopharodon conocephalus*			X
Sacramento squawfish	*Ptyshocheilus grandis*		X	X
Golden shiner	*Notemigonus crysoleucas*		X	X
Fathead minnow [2/]	*Pimephales promelas*		X	
Carp	*Cyprinus carpio*		X	X
Sacramento sucker	*Catostomus occidentalis*		X	X

Folsom Lake

Folsom lake was created in 1955 when Folsom Dam was completed, impounding the American River. The reservoir is located in Sacramento, Placer and El Dorado Counties and receives water from a drainage area of 1,861 square miles. The reservoir has a mean surface area of approximately 10,000 acres and a volume of 713,000 acre feet. Mean and maximum depths are 66 and 226 feet, respectively. Water level fluctuation averages 53 feet annually.

The total dissolved solids concentration of the reservoir water is low (46 mg/l) suggesting a relatively low productivity potential. A thermocline develops each year but oxygen is not depleted in the hypolimnion. No chronic water quality problems have been identified.

The Folsom Lake shoreline is steep-sided in the upper reaches of the reservoir and moderately sloped near the dam. The shoreline at maximum storage has a length of 75 miles. Vegetation around the reservoir consists of a mixture of grassland, oak woodland, and chaparral plant communities. Vegetation was cleared from the fluctuation zone of the reservoir before filling. Annual rainfall averages 25 inches at the reservoir.

Power production (as well as flood control, irrigation, and water supply) is an authorized purpose of the project. Electric power generation began in 1955. The Folsom powerplant has a rated capacity of 162,000 Kw.

include 1 boat marina and a total of 23 boat launching lanes at the reservoir. There are 2 campgrounds with 130 units. The Bureau of Reclamation reported 1,526,000 visitor-days at Folsom Lake in calendar year 1980 (USBR files). Fishing accounted for 813,000, 552,000, 354,000 and 763,000 visitor-days in 1975, 1976, 1977, 1978, respectively.

Shasta Lake

Shasta Lake, created in 1944 by the closure of Shasta Dam on the Sacramento River, is California's largest water storage reservoir. It was the first unit constructed of the U.S. Bureau of Reclamation's Central Valley Project. The reservoir is located in Shasta County and receives water from a drainage area of 6,400 square miles. The reservoir has a mean surface area of approximately 29,500 acres and a volume of 4,500,000 acre feet. Mean and maximum depths are 152 and 490 feet, respectively. Water-level fluctuation averages 55 feet annually.

The total dissolved solids concentration of the reservoir water is 102 mg/l suggesting moderate productivity in comparison to that at other Central Valley reservoirs. A deep thermocline develops in the reservoir each year. Chronic water quality problems in the Little Squaw Creek and Backbone Creek arms of the reservoir have resulted in numerous fish kills. High the rainbow trout, the reservoir is planted annually with brown trout, and, when available, silver and chinook salmon.

The present warmwater fishery is supported by smallmouth bass, northern largemouth bass, bluegill, black crappie, channel catfish, white catfish, and brown bullhead. These species are self-sustaining and no stocking is conducted at this time. Alabama spotted bass and Florida strain largemouth bass were introduced in 1981 and 1982 in an attempt to improve the bass fishery.

Three physical factors limiting the potential of the fishery are: (1) water-level fluctuation during the spawning season limits the reproductive success of centrarchids, (2) limited cover for centrarchids, and (3) heavy metals pollution entering Squaw Creek arm of the reservoir results in occasional fish kills.

Sixteen concessionaires operate facilities at Shasta Lake. Presently, 653 overnight campground units are available. There are 7 boat launching ramps providing a total of 13 lanes. For calendar year 1980, recreation use at Shasta Lake was 1,876,500 visitor-days according to Bureau of Reclamation statistics (USBR files). Fishing accounted for 3,862,000, 1,756,000, 1,016,000, and 1,834,000 visitor days in 1975, 1976, 1977 and 1978, respectively.

TABLE 2

A-1 Study

Reservoir Operation Schedules

Alternatives

Code	Name	Schedule
A1A	A1 BASE	Base study, Existing agreements all years
A1B	A1 ALT 1	6,000 Wet, Normal & Dry, 4,500 Critical
A1C	A1 ALT 2	6,000 Wet & Normal, 4,500 Dry, Existing Critical
A1D	A1 ALT 3	6,000 Wet & Normal, Existing Dry & Critical
A1E	A1 ALT 4	6,000 Wet & Normal, 4,500 Dry & Critical
A1F	A1 20 BASE	Base Study, Existing agreements all years
A1G	A1 20 A1	6,000 Wet & Normal, 4,500 Dry & Critical
A1H	A1 20 A2	6,000 Wet & Normal, 4,500 Dry, Existing Critical
A1I	A1 20 A3	6,000 Wet & Normal, Existing Dry & Critical
A1J	A1 20 A4	6,000 Wet, Normal & Dry, 4,500 Critical

in the 1980 level of development. Similarly, we compared mean standing crop values for all years under each alternative operation schedule in the 2020 level of development (Table 3).

Results of the above comparisons indicate little difference in standing crop values when comparing alternatives within a single water year or for all water years combined. This held true for both the 1980 and 2020 levels of development for Clair Engle, Folsom and Shasta reservoirs.

There was no significant difference between alternative operation schedules for the mean standing crop values of all years for each reservoir. This was true for both 1980 and 2020 levels of development.

Comparison of Total Annual Sport harvest

We used Equation E from the U.S. Fish and Wildlife Service Reservoir Research Program (USFWS, 1981) to estimate total annual sport fish harvest (in pounds per acre) as follows:

E) Estimation of total annual sport fish harvest - selected reservoir types

log (total sport fish harvest in pounds per acre) = - 0.3892 - 0.1519 log (area) + 0.2027 log (dissolved solids) + 0.9796 log (growing season) - 0.3055 log (age)

N = 46 R^2 = 0.69

This equation was applicable to reservoirs less than 70,000 acres, with total dissolved solids less than 600 ppm. and a growing season greater than 140 days. Total annual sport fish harvest values were determined for Clair Engle, Folsom and Shasta reservoirs for 49 years of record (1922-1970) and for selected years representing dry (1923), critical (1931 and 1934), normal (1954) and wet (1958) years under five different operation schedules for 1980 and 2020 levels of development. We also looked at changes in sport fish harvest values as the reservoirs aged up to 100 years (Tables 4, 5 and 6).

TABLE 5.

FOLSOM RESERVOIR

Estimation of total annual sport harvest lbs/acre at a reservoir of:

	Age	1980 ALT. BASE	1980 ALT. 1	1980 ALT. 2	1980 ALT. 3	1980 ALT. 4	MEAN YEAR 1	2020 ALT. BASE	2020 ALT. 1	2020 ALT. 2	2020 ALT. 3	2020 ALT. 4	MEAN YEAR 1
(1923)	1 year	42.8	42.4	42.8	42.7	42.8	42.7	42.1	42.1	42.1	41.8	42.1	42.0
	25	39.7	34.4	34.7	34.7	34.7		34.2	34.2	34.2	33.9	34.2	
	50	12.9	12.8	12.9	12.9	12.9		12.7	12.7	12.7	12.6	12.7	
	100	10.5	10.4	10.5	10.5	10.5		10.3	10.3	10.3	10.3	10.3	
(1931)	1 year	43.8	44.0	42.8	43.8	43.8	43.6	43.9	43.8	43.3	43.8	43.8	43.7
	25	35.5	35.7	35.5	35.5	35.5		35.6	35.6	35.2	35.5	35.6	
	50	13.2	13.3	12.9	13.2	13.2		13.2	13.2	13.1	13.2	13.2	
	100	10.7	10.4	10.5	10.7	10.7		10.8	10.7	10.6	10.7	10.7	
(1934)	1 year	43.8	43.7	43.8	43.8	43.8	43.8	44.3	43.7	43.7	43.8	43.7	43.8
	25	35.5	35.5	35.5	35.5	35.5		35.9	35.5	35.5	35.5	35.5	
	50	13.2	13.2	13.2	13.2	13.2		13.4	13.2	13.2	13.2	13.2	
	100	10.7	10.8	10.7	10.7	10.7		10.9	10.7	10.7	10.7	10.7	
1954	1 year	42.8	42.2	42.8	41.8	42.8	42.5	44.3	42.2	42.2	41.7	42.2	42.5
	25	34.7	34.3	34.7	33.9	34.7		35.9	34.3	34.3	33.9	34.3	
	50	12.9	12.7	12.9	12.6	12.6		13.4	12.7	12.7	12.6	12.7	
	100	10.5	10.7	10.5	10.3	10.3		10.9	10.3	10.3	10.3	10.3	
1958	1 year	42.8	42.1	42.8	42.8	42.8	42.7	42.3	42.1	42.1	41.8	42.1	42.1
	25	34.7	34.5	34.7	34.7	34.7		34.3	34.2	34.2	33.9	34.2	
	50	12.9	12.8	12.9	12.9	12.9		12.7	12.7	12.7	12.6	12.7	
	100	10.5	10.3	10.5	10.5	10.5		10.3	10.3	10.3	10.3	10.3	
ALL	1 Year	42.8	42.7	42.8	42.7	42.8	42.8	42.7	42.5	43.0	42.8	42.5	42.7
	25	34.7	34.7	34.7	34.7	34.7		34.7	34.5	34.9	34.7	34.5	
	50	12.9	12.9	12.9	12.9	12.9		12.9	12.8	13.0	12.9	12.8	
	100	10.5	10.4	10.5	10.5	10.5		10.5	10.4	10.5	10.4	10.4	
		42.8	42.4	42.8	42.7	42.8		42.1	42.1	42.1	41.8	42.1	
		43.8	44.0	42.8	43.8	43.8		43.9	43.8	43.3	43.8	43.8	
		43.8	43.7	43.8	43.8	43.8		44.3	43.7	43.7	43.8	43.7	
		42.8	42.2	42.8	41.8	42.8		44.3	42.2	42.2	41.7	42.2	
		42.8	42.1	42.8	42.8	42.8		42.3	42.1	42.1	41.8	42.1	
		42.8	42.7	42.8	42.7	42.8		42.7	42.5	43.0	42.8	42.5	
YEAR 1 MEAN		43.1	42.9	43.0	42.9	43.1		43.3	42.7	42.7	42.6	42.7	

For each reservoir and each type of water year, we compared total annual sport harvest value under the different alternative operation schedules. We did this for both 1980 and 2020 levels of development. We also compared 1980 and 2020 annual sport harvest values of a single type of water year and same alternative to see trends with development change. Finally, we compared the year 1 mean sport harvest values under each alternative operation schedule. We did this for both 1980 and 2020 development levels.

The results of this analysis indicate that for the three reservoirs studied there were no significant differences in annual sport harvest values between any of the alternative operation schedules for any of the selected water years. This was true for both 1980 and 2020 development levels. Similarly there was no significant difference in the year 1 mean annual sport harvest values for all selected type water years between the various alternative operation schedules. This was true for both the 1980 and 2020 levels of development.

The mean values, based on all years of record, may be considered as reasonable estimates of actual fish production. The values calculated for the critical year periods provide comparative numbers only and are not accurate estimates of what annual sport harvest would be in response to a sudden change in reservoir operation. Instead these values reflect harvest levels which would occur over a long-term period if the critical year conditions were maintained as the norm.

TABLE 7. RESERVOIR FLUCTUATION (1922-1970)
NUMBER OF OCCURANCES
MARCH-JUNE

ALT.	CLAIR ENGLE			FOLSOM			SHASTA		
	MAR/APR	APR/MAY	MAY/JUNE	MAR/APR	APR/MAY	MAY/JUNE	MAR/APR	APR/MAY	MAY/JUNE
A1A	9	5	0	7	1	0	9	0	0
A1B	7	4	0	11	2	0	9	0	2
A1C	7	4	0	13	1	0	11	0	2
A1D	9	5	0	13	1	0	8	0	0
A1E	8	4	0	12	2	0	8	0	1
SUBTOTAL	40	22	0	56	7	0	45	0	5
A1F	9	7	1	9	1	0	0	1	3
A1G	9	5	0	6	1	0	10	0	1
A1H	9	7	1	7	2	0	9	0	1
A1I	9	7	0	12	1	0	6	0	0
A1J	8	6	0	8	1	2	8	1	2
SUBTOTAL	44	32	2	42	6	2	42	2	7
TOTAL	84	54	2	98	13	2	87	2	12

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3. Clair Engle, Folsom and Shasta reservoirs all showed water level fluctuations greater than 20 feet during critical centrarchid spawning periods under all alternative operation schedules in both 1980 and 2020 development levels. However, information on daily fluctuations was not available, so we were unable to reach any firm conclusions on what effects these fluctuations may have on centrarchid fish population levels.

APPENDIX F

APPENDIX F

AVERAGE ANNUAL MORTALITY REDUCTION (NET)

ALTERNATIVE 1

1980 : .27(1.5+(-.3))/2+.48(-.3+(-13.9))/2+.25(-13.9+(-9.1))/2 =
.1620% -3.4080% -2.8750%
= -6.1210%

2020 :.31(.9+0)/2+.36(0+(-1.8))/2+.33((-1.8)+3.6)/2
.1395% -.3240% .2970%
= .1125%

ALTERNATIVE 2

1980 :.27(1.5+0)/2+.46(0+(-11.4))/2+.27((-11.4)+(-9.6))/2
.2025% -2.6220% -2.8350%
= -5.2545%

2020 :.31(.9+0)/2+.4(0+2.1)/2+.29(2.1+11.3)/2
.1395% .4200% 1.9430%
= 2.5025%

ALTERNATIVE 3

1980 :.27(1.5+0)/2+.48(0+(-9.3))/2+.25((-9.3)+(-9.0))/2
.2025% -2.2320% -2.2875%
= -4.3170%

2020 :.29(.9+0)/2+.38(0+2.1)/2+.33(2.1+1)/2
.1305% .3990% .5115%
= 1.0410%

ALTERNATIVE 4

1980 :.27(1.5+0)/2+.5(0+(-7.1))/2+.23((-7.1)+(-9.2))/2
.2025% -1.7750% -1.8745%
= -3.4470%

2020 :.29(.9+0)/2+.27(0+5)+.44(5+1.2)/2
.1305% .6750% 1.3640%
= 2.1695%

NOTE: 1980 SCENARIO ASSUMED TO EQUAL 1990 (YR # 1 OF PROJECT) SCENARIO
NOTE: "-" FIGURES REPRESENT INCREASES IN MORTALITY